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AIRCRAFT MANEUVERS FOR THE EVALUATION OF FLYING QUALITIES AND AGILITY

VOL 1: MANEUVER DEVELOPMENT PROCESS AND INITIAL MANEUVER SET

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13. ABSTRACT (*Maximum 200 words*)
A set of aircraft maneuvers has been developed to augment evaluation maneuvers used currently by the flying qualities and flight test communities. These maneuvers extend evaluation to full aircraft dynamics throughout the aircraft flight envelope. As a result, a tie has been established between operational use and design parameters without losing control of the aircraft evaluation process.

Twenty maneuvers are described as an initial set to examine primarily high-angle-of-attack conditions. Perhaps as important as the maneuvers themselves is the method used to select them.

These maneuvers will allow direct measurement of flying qualities throughout the flight envelope instead of merely comparing parameters to specification values.

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Foreword

As flight control systems become capable of providing a variety of aircraft response types and aircraft flight envelopes expand to include a wider range of angle of attack and speed, the ability to predict flying qualities becomes increasingly difficult. Traditional parameters, such as modal characteristics and time delay, cannot totally capture the relationship of aircraft dynamics, task performance and pilot workload. The success of the Handling Qualities During Tracking flight test technique led to the thought that a series of demonstration maneuvers could be defined for a variety of tasks which would augment the normal aircraft flying qualities description. In order to be useful, such maneuvers must be well-defined and suited to testing, must relate to the operational use of the vehicle and must be sensitive to parameters used in the design process.

The research documented in this four-volume report series has developed a process by which these maneuvers can be defined and validated as well as an initial set of maneuvers aimed primarily at agility and the high-angle-of-attack flight regime. A key word here is initial, limited resources did not allow this effort to address all aircraft types or missions. It is hoped that as various agencies and companies conduct their own research, they will develop additional or modified maneuvers and add them to this existing set. This process will allow the maneuvers to keep pace with the changes in aircraft technology and operational missions and tasks. New maneuvers should be sent to WL/FIGC_2, WPAFB OH, 45433-7531. An updated set of maneuvers and lessons learned will be available either by mail or electronically through the ARPANET computer network. For details, contact Tom Cord at (513) 255-8674. The resulting maneuver set will provide a basis from which demonstration maneuvers for the verification section of Mil-Std-1797B can be defined.

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Preface

This series of reports proposes aircraft maneuvers and general guidelines for the piloted evaluation of aircraft flying qualities and agility. These maneuvers augment rather than replace existing flying qualities evaluation techniques and are aimed primarily at expanded flight envelopes. A process to develop new evaluation maneuvers that link operational requirements to the design process is outlined and key concepts are identified. A format for documenting and selecting useful evaluation maneuvers is also described. Finally, the evaluation maneuvers and data demonstrating their sensitivity to design parameter variations are described.

This documentation is organized into a sequence of four reports. The first report, subtitled "Maneuver Development Process and Initial Maneuver Set," includes a detailed description of the research conducted as well as a summary of the results. It describes the maneuver development process used during this research and key considerations for developing new evaluation maneuvers. A brief summary of typical results observed for each maneuver tested is also included. The second report, subtitled "Maneuver Descriptions and Selection Guide," is a stand-alone document that describes the maneuvers tested during this research. It documents the intent of each maneuver, the aircraft attributes isolated, the techniques required to fly the maneuver, as well as presenting a cross reference to help select the most valuable maneuvers for aircraft evaluation. The second report is the beginning of a standard maneuver reference guide that will contain a wide variety of evaluation maneuvers for use throughout configuration development and flight test. It is recommended that new and existing evaluation maneuvers be added to this report to provide a source of evaluation maneuvers for the design and test community. The third report, subtitled "Simulation Data," consists of detailed information on the design parameter variations tested, subsequent statistical analyses conducted on the simulation data, and pilot comments and ratings from the testing. The fourth report, subtitled "Flight Test Plan," includes a preliminary test plan for the in-flight validation of the evaluation maneuvers.

Acknowledgments

This research was sponsored by the US Air Force Wright Laboratory under contract number F33615-90-C-3600. The work was performed from September 1990 through June 1993. We would like to thank Tom Cord of FIGC_2 who diligently pursued the concept of a standard evaluation maneuver set and served as technical monitor of this contract. Valuable guidance and support was received from David Riley and Kevin Citurs of McDonnell Douglas Aerospace (MDA) who served as program managers. The results of this program were due greatly to the wide range of experience and excellent cooperation received from those who participated in the review team and/or the simulations. In particular, valuable contributions were received from: Fred Austin, Jeff Beck, Tom Cord, Bryson Lee, Mark Shackelford, and Bob Wilson of the US Air Force; David Kennedy, Bill McNamara, David Prater, and Chuck Sternberg of the US Navy; Chris Hadfield of the Canadian Air Force; Jim Buckley, Kevin Citurs, Ron Green, Tom Lillis, David Riley, and Fred Whiteford of MDA; Bill Hamilton of Hamilton & Associates, Inc.; Robert Shaw of FCI, Inc.; and John Hodgkinson, Jeff Preston, and Ken Rossitto of Douglas Aircraft Company. Key support for the flight simulation and data analysis efforts conducted under this contract were provided by: Stuart Alsop, Bruce Dike, Dan Dassow, Don Fogarty, Debbie Lambert, Steve Knapp, Scott Sheeley, and the MDA flight simulation staff. Development of the flight test plan was supported by Mike Ludwig, Rod Davis, and Terry Weber of MDA. Finally, valuable general support was provided by Joe Boland of MDA throughout this contract especially during time-critical phases.

Nomenclature

ACTIVE	Advanced Controls Technologies for Integrated Vehicles
AOA	Angle Of Attack
CAP	Control Anticipation Parameter
DACM	Dynamic Acceleration Compute Model
DOE	Design of Experiment
FAPIP	Fighter Airframe Propulsion Integration Predesign
GENAIR	Generic Aircraft
GLOC	g Induced Loss Of Consciousness
HARV	High Alpha Research Vehicle
HQDT	Handling Qualities During Tracking
HUD	Head-Up Display
IRAD	Internal Research and Development
MATV	Multi-Axis Thrust Vectoring
MDA	McDonnell Douglas Aerospace
MuSIC	Multi-System Integrated Controls
PIO	Pilot Induced Oscillation
PRR	Pitch Recovery Rating
PST	Post-Stall
RFCS	Research Flight Control System
S/MTD	STOL and Maneuvering Technology Demonstrator
STEMS	Standard Evaluation Maneuver Set

Chapter 1
Introduction and Summary of Results

Background and Objectives

Many valuable evaluation maneuvers currently exist for heart-of-the-envelope flying qualities testing such as the well established "Handling Qualities During Tracking" (HQDT) techniques[1] and offset landings. However, additional maneuvers are needed as aircraft flight envelopes are expanded to higher angles of attack and as aircraft capabilities are improved through application of technologies such as thrust vectoring and forebody vortex controls. As a result, this effort was devised[2] to extend HQDT techniques and augment current evaluation methods with new maneuvers specifically designed to aid in the evaluation of improved aircraft capabilities such as those shown in Figure 1. Such maneuvers would be used to identify deficiencies while an aircraft is still in the design, development, or flight test stage rather than uncovering problems after a vehicle has entered operational use. These maneuvers were not developed to compare an aircraft against specification parameters, but instead they provide a true evaluation of the flying qualities and agility of an aircraft in an operationally representative environment.

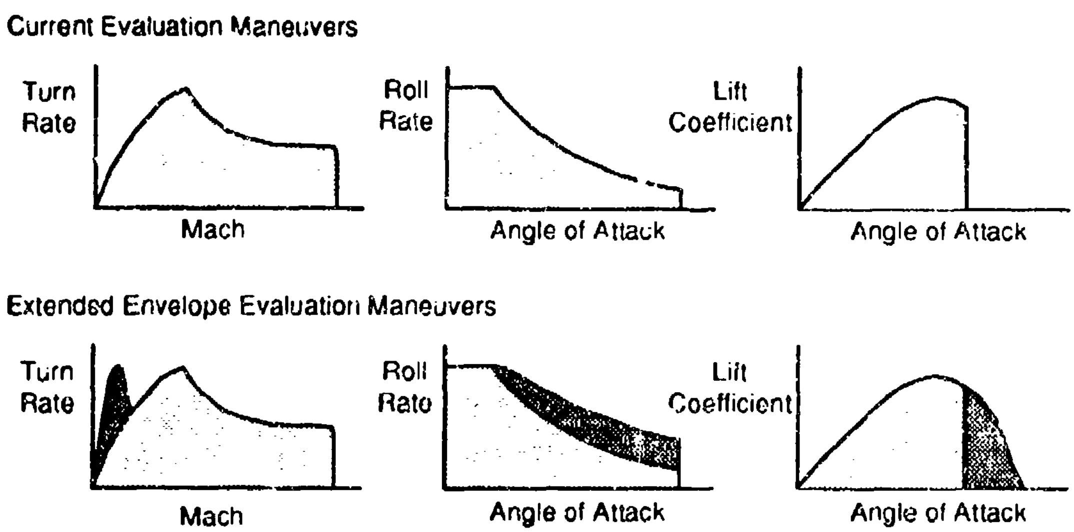


Figure 1. New Maneuvers for the Evaluation of Enhanced Aircraft Capabilities

A key goal during the development of these maneuvers was to establish a link between operational requirements and the design process. This is necessary to ensure that the maneuvers can be used during the design process, Figure 2, while emulating the dynamic requirements observed in an operational environment. This blends operational needs back into a repeatable, useful evaluation maneuver similar to the HQDT techniques. By using an operationally relevant evaluation maneuver, the aircraft design can be evaluated in a fashion more like it will be used by the pilots. True operational relevance is somewhat unlikely for a maneuver that is intended to be repeatable and provide design guidance. However, the Standard Evaluation Maneuver Set (STEMS) maneuvers are designed to require similar dynamic requirements to those needed during operational missions. This is what is meant by the term operationally relevant throughout this report. This research was not intended to be a criteria development effort or a tactical utility study. Instead, a sensitivity between each maneuver and various design parameters was established. Therefore, the designer now has an evaluation tool that can be used to show changes in aircraft flight characteristics during the development phase. Detailed descriptions of the evaluation maneuvers can be found in the second report of this report series.[3] In addition, several of these maneuvers may be suitable for the development of design criteria or tactical utility studies. The detailed data contained in the third report[4] of this report sequence might be useful as a starting point for either of these efforts.

Another objective of this research was to define an effective and efficient maneuver development process so that additional maneuvers could be generated as the need arises. Such a process is desirable because this effort could not define a complete set of evaluation maneuvers. Instead it documents an initial set of standard maneuvers with the hope that other researchers will continue to add useful evaluation maneuvers. The maneuver development process and key concepts used during this contract are considered to be necessary to provide consistently high quality additional maneuvers. This process and these key ideas will help keep STEMS a "living" document as new maneuvers are added for new technologies or to include current evaluation methods.

A final objective of this effort was to develop a preliminary flight test plan. The flight test plan was written to help transition the experience obtained while developing these maneuvers in simulation to a flight test validation program. It is written generically so that it can be modified for any aircraft, but it is aimed towards aircraft with high angle of attack capability. The flight test plan will be summarized in this report and is detailed in Reference 5.

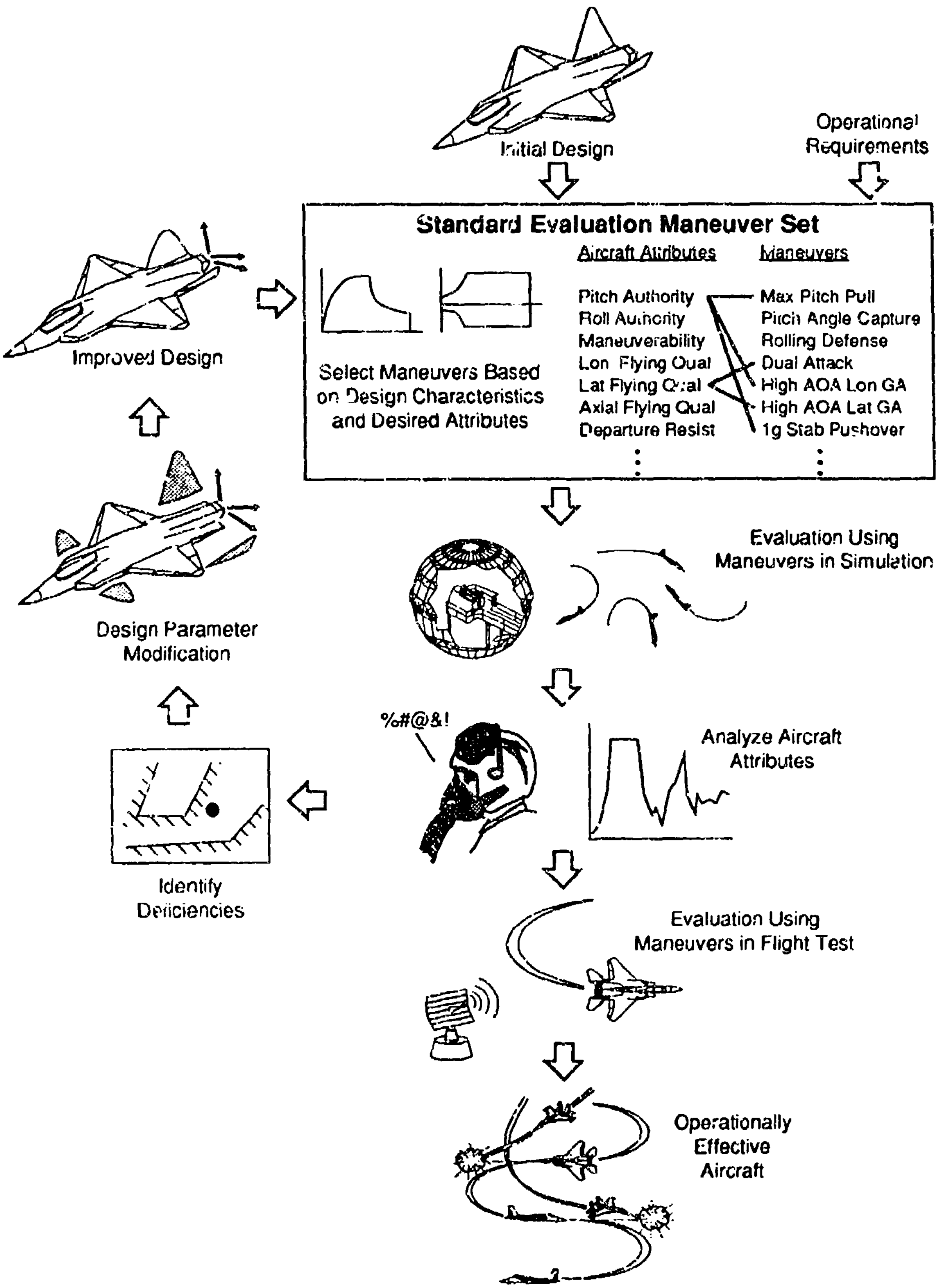


Figure 2. Evaluation Maneuvers Tie Operational Requirements to Design

Program Structure

A two-phase program was used to achieve the above objectives, Figure 3. The first phase was an initial maneuver development phase that included brainstorming and screening efforts. Both pilots and engineers with varying backgrounds worked to develop a large set of potential maneuvers. The maneuvers were conceived from each individual's experience and background. These maneuvers were then discussed, refined, and sorted into a more manageable set to test during Phase II. No flight simulation was conducted during Phase I.

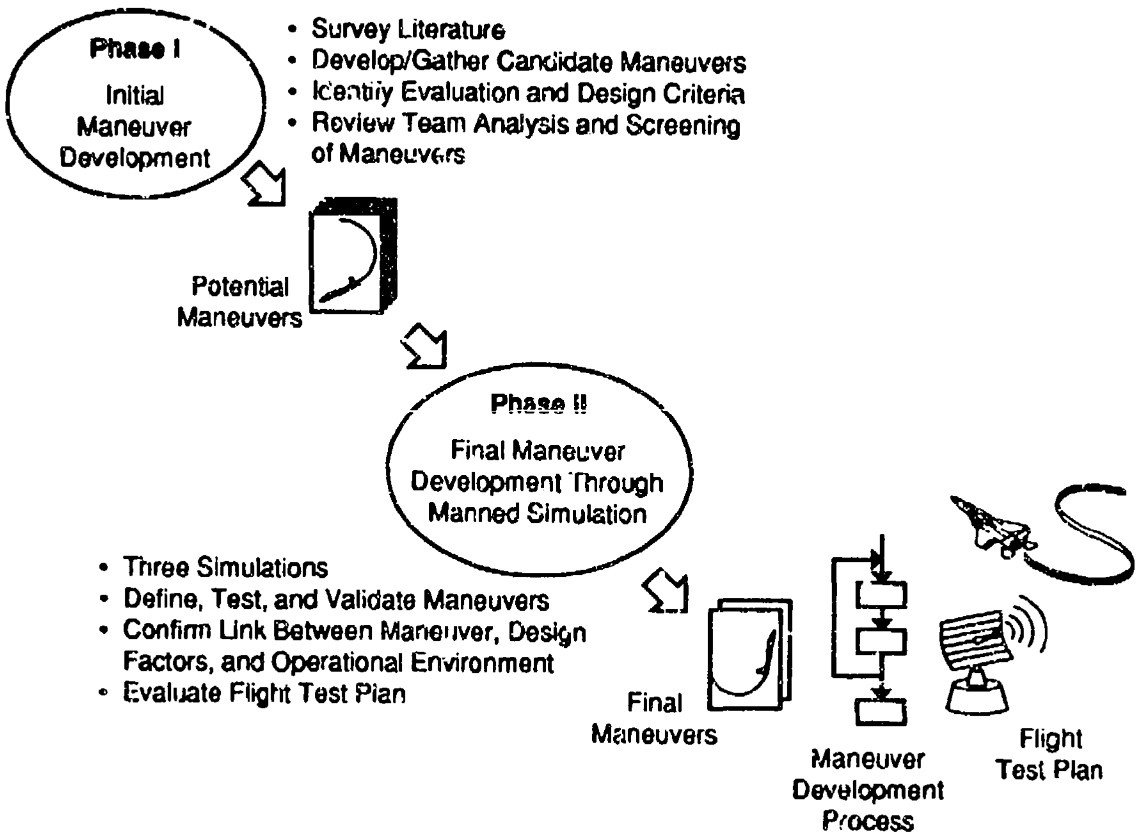


Figure 3. Program Structure

The second phase was used to further develop, refine, and test the maneuvers by means of piloted flight simulation and a data quality review process. Phase II consisted of three simulations with periods of data analysis between, Figure 4. This structure was valuable because it provided for periods of learning between the simulations. The first simulation and subsequent data analysis were structured to be somewhat exploratory to initially test ideas and techniques. The second simulation and data analysis was the primary data gathering effort and the third simulation was used to answer unresolved issues and conduct additional validation testing. The third simulation was also used to evaluate and refine a draft flight test plan.

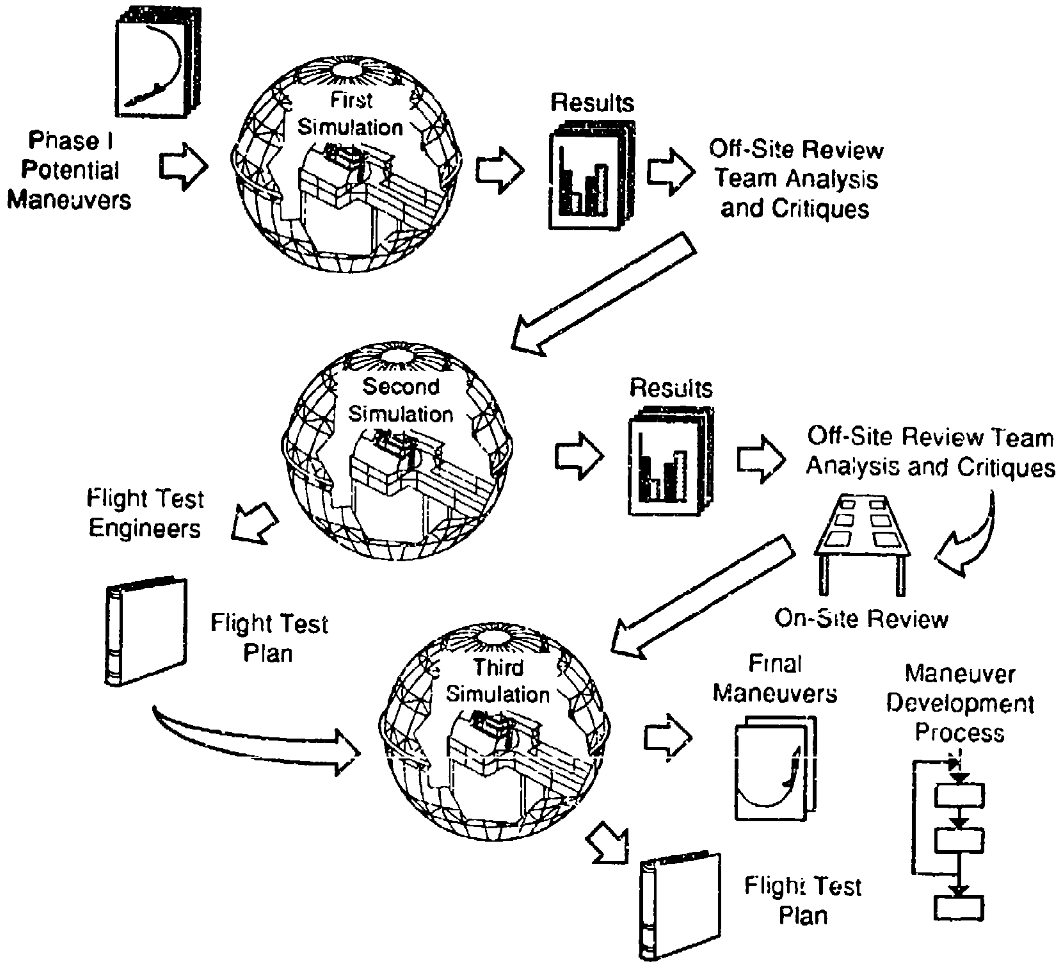


Figure 4. STEMS Three Simulation Effort

A recurring feature throughout this research was the involvement of both government and industry personnel. A Review Team of pilots and engineers was included during the entire contract to evaluate the maneuvers and maneuver development process as well as provide guidance for remaining work. Many members of the Review Team also participated in the simulation efforts. The extensive experience and diverse background among the Review Team members was very beneficial in developing and reviewing the maneuvers. Pilots with both test and operational experience were intentionally included so that the maneuvers could benefit from each expertise. Additionally, the Review Team engineers had varying backgrounds that covered flying qualities, agility, and flight test experience. Obviously there was overlap in the Review Team members' backgrounds, but each had valuable unique experience to offer.

Results

Three primary products were developed during this research: a process to develop new maneuvers, an initial set of evaluation maneuvers, and guidelines to help select existing maneuvers, Figure 5. The maneuver development process can be used to produce evaluation maneuvers that are representative of operational requirements and are sensitive to design parameter variations. The evaluation maneuvers are valuable during design and flight test to evaluate aircraft attributes. Finally, the maneuver selection guidelines can be used to help select the most important maneuvers for the given test objectives.

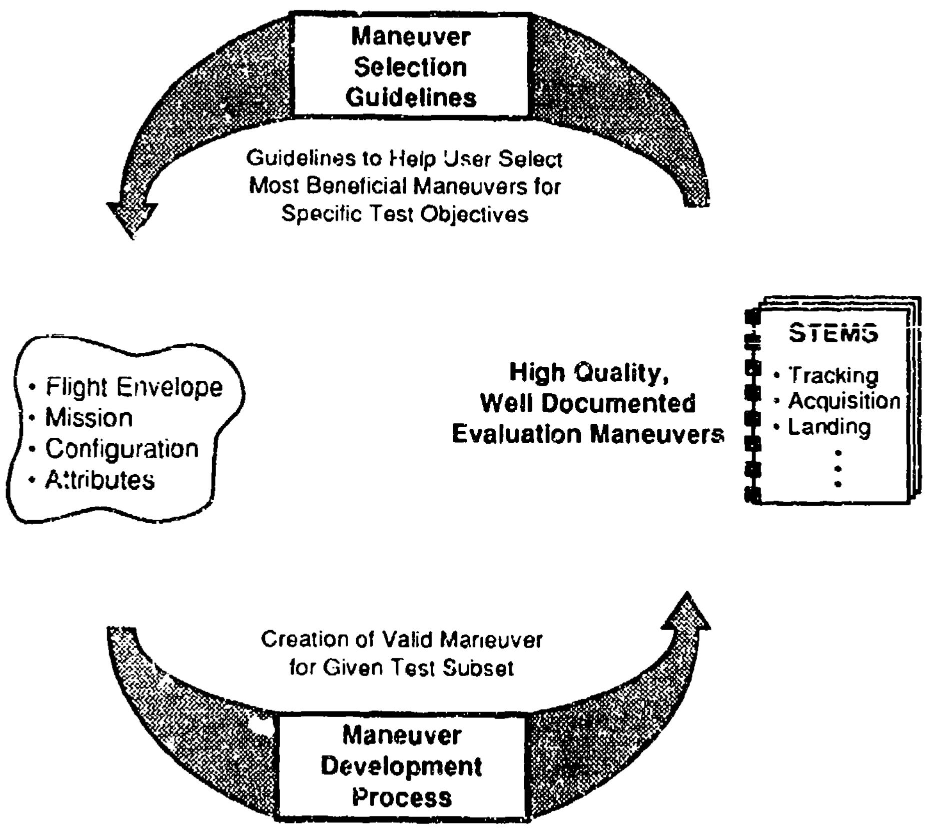


Figure 5. Maneuver Development and Selection

There are several benefits that can be gained through the use of these tools. High quality evaluation maneuvers can be developed more efficiently. The time required to test an aircraft can be reduced by using predefined, well-documented evaluation maneuvers. The time required to plan for a test can be reduced and the quality of the test can be improved by using the maneuver selection guidelines. And most importantly, a more constructive evaluation can be conducted by evaluating key aircraft attributes.

The maneuver development process consists of several key elements as shown in Figure 6. One of the most important ingredients is the involvement of both pilots and engineers throughout the development, refinement, and analysis of each maneuver. It is also beneficial to draw upon a variety of backgrounds including operational, flying qualities, agility, and flight test. The operational experience is especially useful to help tie the maneuver to the requirements of the final user -- the operational pilot. The flight test experience is invaluable to help define repeatable, measurable, and flyable maneuvers. Finally, the use of piloted flight simulation and a data quality review process were also key to efficiently and effectively defining evaluation maneuvers.

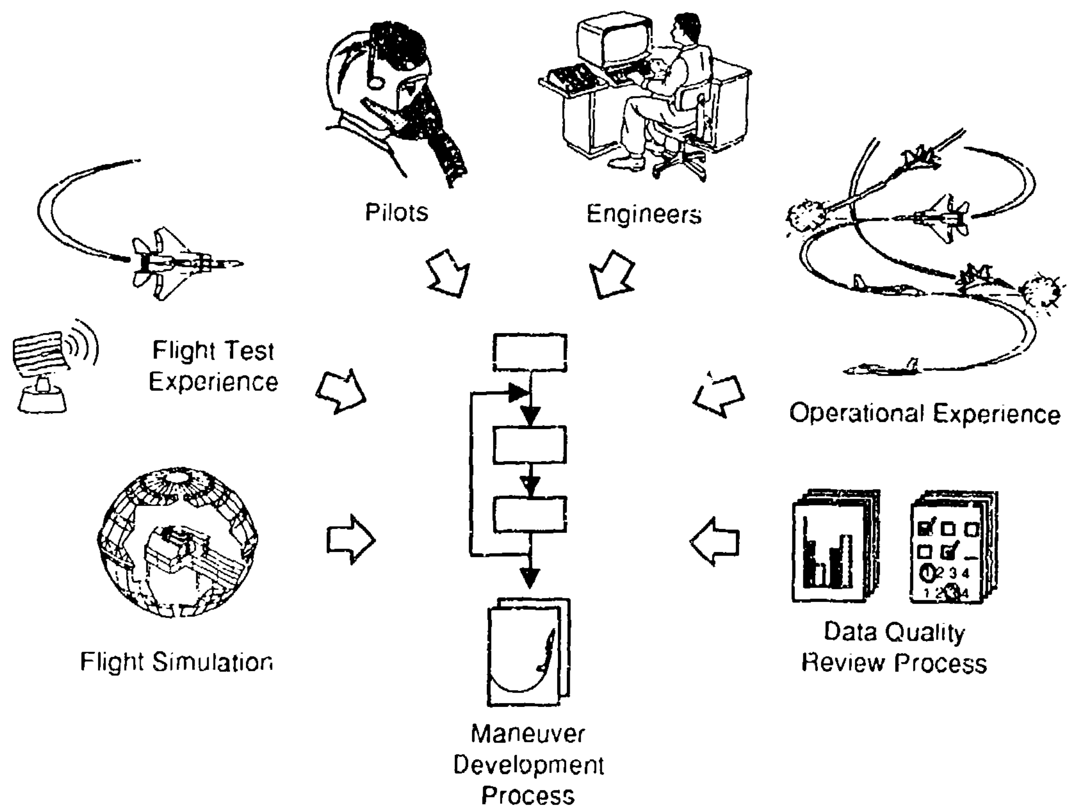


Figure 6. Key Elements Required to Develop Effective Evaluation Maneuvers

Utilization of this maneuver development process resulted in the identification of 20 maneuvers that can be used to evaluate various flying qualities and agility attributes while maintaining a tie to operational requirements. Figure 7 shows some example attributes and operational tasks that are addressed by these maneuvers. These 20 evaluation maneuvers were shown to be repeatable and provide useful data for the design process. Descriptions of these maneuvers have been developed to document the intent of each maneuver, the techniques used to fly the maneuver, and potential variations to the maneuver. These maneuvers are primarily

designed for application to fighter aircraft, and in particular, attributes required for air-to-air combat. Many of the maneuvers were developed to evaluate extended flight envelope capabilities in terms of post-stall/low-speed maneuvering because of relatively recent improvements in aircraft capability in this flight regime. A few maneuvers were developed for heart-of-the-envelope operation and for transport class aircraft to validate this concept over a wider range of aircraft classes and flight phases.

Aircraft Attributes	Operational Tasks
• Longitudinal Flying Qualities • Lateral Flying Qualities • Directional Flying Qualities • Axial Flying Qualities • Multi-Axis Flying Qualities • Pitch Authority • AOA Authority • Roll Authority • Pitch Control Margin • Roll Coordination • Pitch Performance • Roll Performance • Turn Performance • Axial Performance • Maneuverability • PIO Tendencies • Departure Resistance • Frontside/Backside Operation	• Guns Tracking • Shift Targets • Turn Reversal • Weapons Acquisition • Nose Intimidation • Guns Defense • Collision Avoidance • Vertical Lead Turn • Missile Jink • SAM Break • Vertical Reposition • Vertical Attack • Attack Abort - Bugout • Min Time Nose High Reversal • Aerial Refueling • Formation Flying • Precision Landing • Side-Step Approach & Landing

Figure 7. Example Aircraft Attributes and Operational Applications

The maneuvers developed under this research range in complexity and character as shown in Figure 8. Some maneuvers tend to isolate a single axis while others are multiple-axis tasks. The nature of the maneuvers varies from pure open-loop tasks to tight closed-loop tracking tasks. And the pilot technique varies from structured (technique precisely defined) to unstructured (freestyle technique allowed). Because of the wide range of maneuvers available, the best maneuver to use for an evaluation depends upon the data and information that is being sought. Some maneuvers were found to be more useful for qualitative data gathering whereas others were much better suited for quantitative analyses. A maneuver selection guide was developed to help the user select potentially useful evaluation maneuvers. Once the user identifies the aircraft characteristics to be tested, the selection guide and additional information provided with the maneuver descriptions can be used to help select the best maneuvers. Descriptions of the maneuvers and the maneuver selection guide are included in Reference 3.

Maneuver Number and Name	Env.		Axis			Data		Precision				Type		
	Conventional	High AOA	Longitudinal	Lateral-Directional	Axial	Quantitative	Qualitative	No Capture	Gross Capture	Moderate	Tight Control	Individual Maneuver	Maneuver Sequence	Freestyle Maneuver
1. Tracking During High AOA Sweep		√	√	√			√				√	√		
2. High AOA Tracking		√	√	√			√				√	√		
3. High AOA Lateral Gross Acquisition		√		√		√	√			√		√	√	
4. Dual Attack	√	√	√	√			√			√	√		√	√
5. Rolling Defense		√	√	√		√		√				√		
6. Maximum Pitch Pull	√	√	√			√		√				√		
7. Nose-Up Pitch Angle Capture	√	√	√			√	√			√		√	√	
8. Crossing Target Acq. and Tracking	√	√	√	√			√			√	√		√	√
9. Pitch Rate Reserve		√	√			√		√				√		
10. High AOA Longitudinal Gross Acq.		√	√			√	√			√		√	√	
11. Sharkenhausen	√	√	√	√		√	√			√	√			√
12. High AOA Roll Reversal		√		√		√		√				√	√	
13. High AOA Roll and Capture		√		√		√	√			√		√	√	
14. Minimum Speed Full Stick Loop	√	√	√		√		√	√					√	
15. Minimum Time 180° Heading Change	√	√	√	√	√		√		√					√
16. 1-g Stabilized Pushover		√	√			√		√				√		
17. J-Turn		√	√	√			√		√				√	
18. Tanker Boom Tracking	√		√	√	√		√			√	√	√		
19. Tracking in Power Approach	√		√	√	√		√			√	√	√	√	
20. Offset Approach to Landing	√		√	√	√		√			√	√	√	√	

Figure 8. General Charactoristics of the Initial STEMS Maneuvers

The maneuvers shown in Figure 8 were developed to allow the evaluation of a range of flying qualities and agility characteristics. In particular, an attempt was made to build upon the recent agility maneuver research conducted in References 6 and 7. However, the maneuvers developed under this contract do not define a complete set of evaluation maneuvers. These maneuvers augment existing evaluation maneuvers, and therefore they do not test a comprehensive set of aircraft attributes. A much wider selection of maneuvers would be required to thoroughly evaluate an aircraft. Therefore, it is recommended that existing evaluation maneuvers and newly developed maneuvers be continually added to STEMS to increase its range of applicability. Any additional maneuvers or experiences using STEMS should be forwarded to Wright Laboratory/FIGC_2, where the STEMS maneuver reference guide[3] will be maintained and distributed.

Chapter 2
Maneuver Development Process

A maneuver development process was exercised and refined during this research. This maneuver development process is recommended as an effective and efficient method to develop aircraft maneuvers. This chapter summarizes the process, lessons learned, and key elements required to develop high quality evaluation maneuvers. Chapter 4 will document how this maneuver development process evolved and how 20 evaluation maneuvers were developed and tested during the refinement of this process.

Maneuver Development Process Overview

The maneuver development process is summarized in Figure 9 and will be described in detail in the following sections. Prior to beginning the development of a new maneuver, details of the aircraft characteristics, such as the flight envelope, mission, configuration, and other attributes, must be specified so that the resulting maneuver will meet the test objectives. The first step in the maneuver development process is to define further these aircraft characteristics and propose candidate maneuvers that might meet the test objectives. These candidate maneuvers are then screened to identify the most promising ones. The next step utilizes simulation to further develop and refine the candidate maneuvers. A data quality review is incorporated into this step to ensure that the maneuver produces sufficient data to be useful during design. The final step is used to validate the maneuver through additional simulation and in-flight testing. Also, a very important part of the last step is the documentation of the final evaluation maneuver. Anyone who develops or uses an evaluation maneuver is encouraged to document their results to Wright Laboratory/FIGC_2 for incorporation into STEMS.

Candidate Maneuver Definition and Screening

The first step in the maneuver development process is designed to explore a range of potential maneuvers and select the most promising ones for further development. This requires the involvement of both engineers and pilots with design, flight test, operational, flying qualities, and agility experience as indicated in Figure 10. A variety of backgrounds is beneficial to help provide a wider selection of potential maneuvers and concepts.

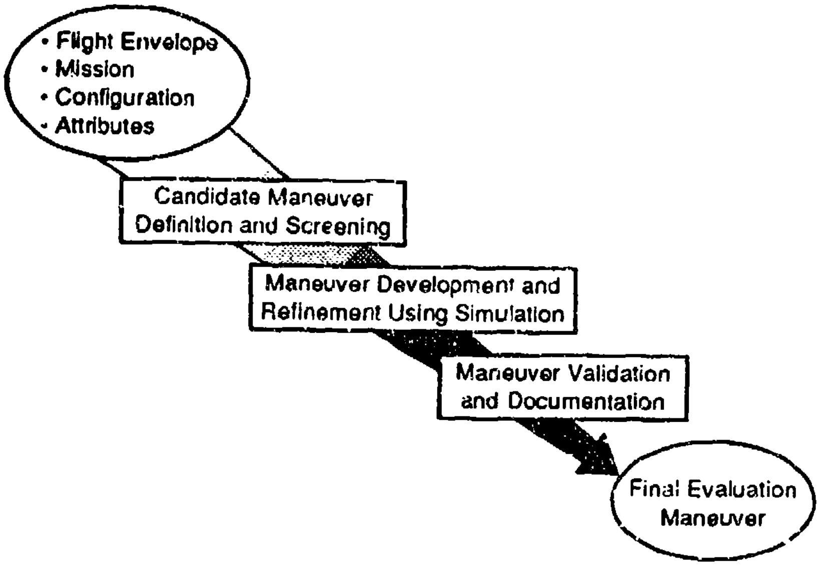


Figure 9. Maneuver Development Process

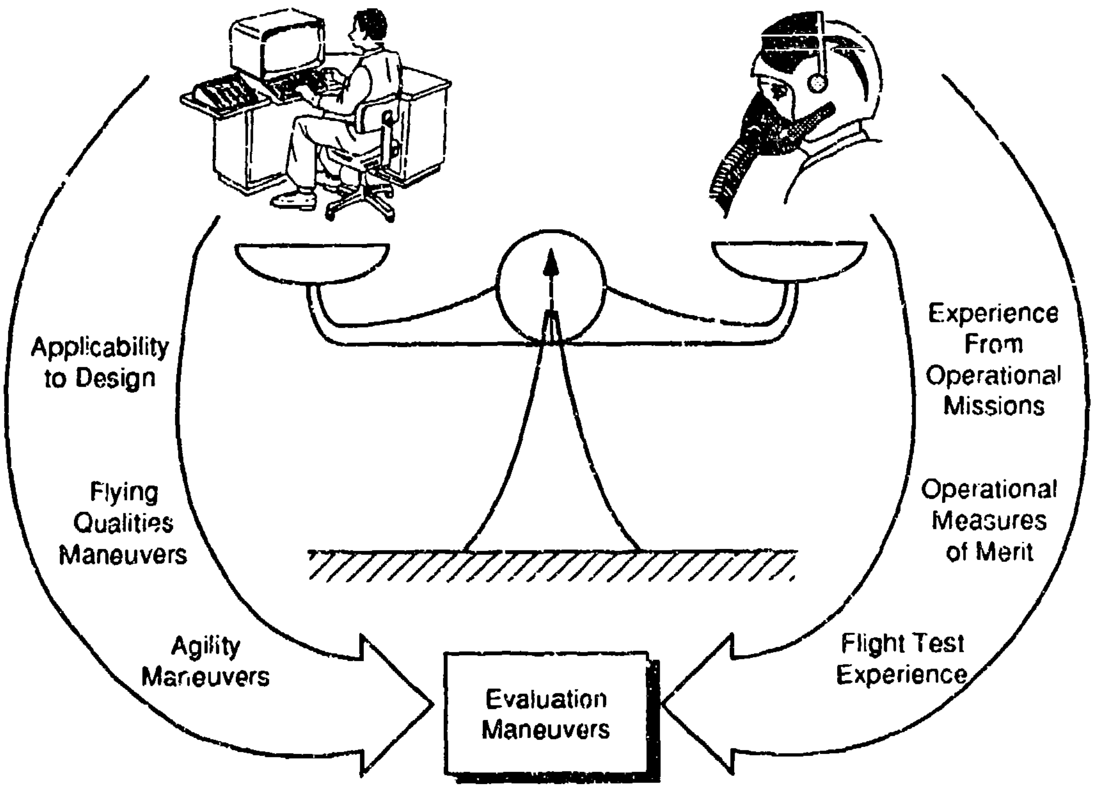


Figure 10. Engineers and Pilots Are Needed to Develop Evaluation Maneuvers

The aircraft characteristics to be evaluated must be defined first. Specific attributes, such as roll authority or Pilot Induced Oscillation (PIO) tendencies, should be identified to help evaluate if the data generated from the maneuver isolates the characteristics of interest. Figure 11 shows a list of attributes that adequately encompass the initial set of evaluation maneuvers. This list of attributes should grow as additional maneuvers are added to STEMS. Potential operational scenarios that require the desired attributes should also be identified at this time. Some example operational scenarios are listed in Figure 12. A stronger tie to operational requirements can be made if operational scenarios are considered throughout maneuver development and refinement. Initial maneuver concepts can then be developed from these operational scenarios and desired test attributes by using "brainstorming", literature searches, and experience. At this stage, the maneuvers may be very "sketchy" and several maneuver concepts should be proposed.

• Longitudinal Flying Qualities	• Pitch Performance
• Lateral Flying Qualities	• Roll Performance
• Directional Flying Qualities	• Turn Performance
• Axial Flying Qualities	• Axial Performance
• Multi-Axis Flying Qualities	• Maneuverability
• Pitch Authority	• Energy Maneuverability
• Roll Authority	• PIO Tendencies
• Pitch Control Margin	• Departure Resistance
• Roll Coordination	• Frontside/Backside Operation

Figure 11. Example Aircraft Attributes

• Guns Tracking	• SAM Break
• Shift Targets	• Vertical Reposition
• Turn Reversal	• Vertical Attack
• Weapons Acquisition	• Attack Abort - Bugout
• Nose Intimidation	• Min Time Nose High Reversal
• Guns Defense	• Aerial Refueling
• Collision Avoidance	• Formation Flying
• Vertical Lead Turn	• Precision Landing
• Missile Jink	• Side-Step Approach & Landing

Figure 12. Example Operational Scenarios

A screening process is then conducted to identify strong candidate maneuvers for further development and refinement. One of the key goals of the maneuver development process is to maintain a link between design and operation, so this link should be evaluated in the screening process. Figure 13 is a form that summarizes some of the key questions that should be considered. A qualitative evaluation must be performed at this point because the maneuvers have not been fully defined and simulation data is not yet available. However, the maneuver's

potential for operational relevance and its suitability for design and engineering use should be considered. The applicability of the maneuver throughout the development process can also be factored into the screening process. A maneuver is more valuable if it can be used from early developmental simulations through to flight test. Finally, potential problems and issues such as human factors considerations or requirements for specialized displays should be identified. These issues may be strong enough to eliminate a maneuver from further consideration or may simply indicate the need to explore certain issues during simulation.

Operational Relevance:		Yes	No
1. Are dynamic conditions and pilot activity representative of operational use?		☐	☐
2. Does the maneuver require use of an extended flight envelope?		☐	☐
3. Is the maneuver useful for evaluation of current aircraft?		☐	☐
4. Is the maneuver useful for evaluation of future aircraft?	6 5 4 3 2 1	☐	☐
5. Link to operational use	Strong ☐ ☐ ☐ ☐ ☐ ☐ Weak		

Suitability for Design/Engineering Use:		Yes	No
6. Is the maneuver meaningful/interpretable in parameters useful to designers?		☐	☐
7. Does the maneuver produce data of sufficient magnitude to guide modification of the design?		☐	☐
8. Can the maneuver be used to produce pilot opinion ratings (such as CHR)?	6 5 4 3 2 1	☐	☐
9. Evaluation of flying qualities	Strong ☐ ☐ ☐ ☐ ☐ ☐ Weak		
10. Evaluation of agility	Strong ☐ ☐ ☐ ☐ ☐ ☐ Weak		
11. Qualitative data generated	High ☐ ☐ ☐ ☐ ☐ ☐ None		
12. Quantitative data generated	High ☐ ☐ ☐ ☐ ☐ ☐ None		
13. Pilot comment data	Strongly Tied to Design Process ☐ ☐ ☐ ☐ ☐ ☐ None		

Additional Concerns:		Yes	No
14. Is the maneuver well defined and repeatable?		☐	☐
15. Can entry/exit conditions be readily established?	6 5 4 3 2 1	☐	☐
16. Displays required/pilot cues necessary	Conventional ☐ ☐ ☐ ☐ ☐ ☐ Unique		
17. Difficulty to fly maneuver	Easy ☐ ☐ ☐ ☐ ☐ ☐ Difficult		

Comments:

Please Circle Your Overall Rating of This Maneuver:

1. Strong evaluation maneuver, definitely part of the final set of maneuvers.
2. Possibly good maneuver, needs additional testing or refinement.
3. Inconclusive, modifications or additional testing required.
4. Possibly poor maneuver, results currently inconclusive but not promising.
5. Poor evaluation maneuver, do not continue testing.

Figure 13. Maneuver Evaluation Form

All of the candidate maneuvers should be examined using the above considerations. The candidate maneuvers that most closely match the test objectives can then be singled out for further development in simulation. However, even good candidate maneuvers may have some

weak points. The quality of the final evaluation maneuver can be improved by working on these weak points during simulation development of the maneuver.

Maneuver Development and Refinement Using Simulation

The development and refinement of a candidate maneuver requires periods of simulation, data analysis, and maneuver evaluation as diagrammed in Figure 14. The maneuver concepts developed during the Candidate Maneuver Definition and Screening process tend to be vaguely defined and need to be further developed during simulation. This is initiated by formulating more precise maneuver descriptions from the initial concepts and defining the data to be collected. A nominal set of aircraft dynamics can be selected for the maneuver refinement process. The specific aircraft dynamics chosen are not critical; however, they should be representative of the test aircraft. Pilots and engineers can then refine the maneuver by quickly trying various techniques during simulation. The objectives of the maneuver refinement are to increase the flyability and repeatability, improve the quality of data generated, and enhance the operational relevance of the maneuver. Additionally, Cooper-Harper Rating[8] performance criteria should be developed for flying qualities evaluation maneuvers.

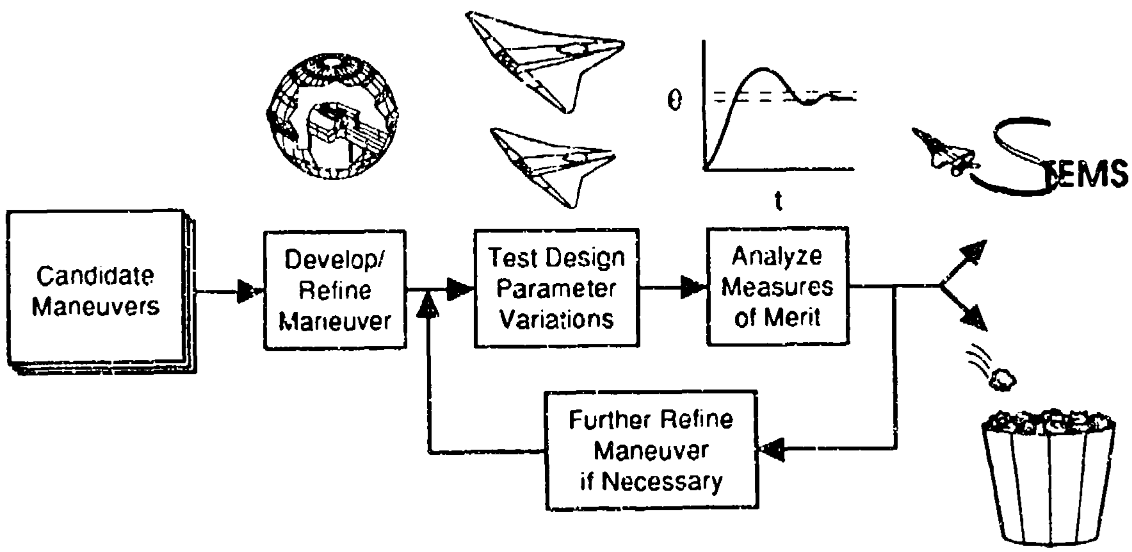


Figure 14. Phase II Maneuver Development Process

Variations in design parameters are tested after the maneuver has been sufficiently refined and developed. Design parameters that are pertinent to the attributes being tested should be selected and appropriately-sized variations should be defined. These variations must be large enough that a resulting change can reasonably be expected. The variations can be based on MIL-STD-1797A[9] and other design guidance and should be large enough that they could be

expected to alter the flying qualities from Level 1 to Level 2 or from Level 2 to Level 3. A test matrix can be developed after choosing the design parameters and their ranges of variation. A full factorial matrix (test every combination) or more efficient Design of Experiment[10] (DOE) or Taguchi[11] methods can be used to develop the test matrix. The design parameter variations are then evaluated during simulation using a blind test that includes at least two pilots.

After gathering simulation data, the maneuver is evaluated for its ability to generate reliable information for design guidance and its ability to isolate the desired test attributes. Time history data, pilot comments, and pilot ratings (when appropriate) should be examined for their sensitivity to design parameter variations and to pilot variability. The time history data can be used either in a raw form to compare pilot inputs, control surface activity, and aircraft states, or it can be processed into numerical measure of merits such as maximum roll rate or time to capture. All of the simulation data is then used to determine if the maneuver can be used to reliably identify design deficiencies. The simulation data should exhibit a sensitivity to design parameter variations and an insensitivity to pilot variability in order for the maneuver to be used with confidence during the design process. The data quality can be examined in various forms such as statistical analyses of measure of merit data, graphical display of time history and pilot rating data, and comparisons of pilot comments.

Quantitative and/or qualitative data may be obtained with a maneuver. The ability to generate quantitative data can be gauged by the quality of measure of merit data obtained with the maneuver. Measures of merit, such as time to capture or maximum pitch rate, can be calculated from the simulation time history data. Statistical techniques are then used to evaluate the amount of variability in the data and thereby judge the quality of quantitative data generated from the maneuver. The change in each measure of merit that is due to a design parameter variation should be compared to the change due to pilot variability. If the measures of merit are much more sensitive to design parameter changes than to differences in pilots, then quantitative data can be used for design guidance. Various methods are available to perform this analysis and a detailed example of one technique is included in Chapter 4.

Additional qualitative data, such as pilot comments, pilot ratings[12] and answers to questionnaires, should be gathered during simulation and considered for their value to the design process. An example pilot comment card that is helpful to evaluate the candidate maneuver is shown in Figure 15. The answers to these questions and the pilot evaluations during the design parameter testing should be reviewed for sensitivity to design parameter variations and insensitivity to pilot variability just like the numerical measure of merit data. If

the pilot comments and ratings successfully correlate to the design parameter variations, then the maneuver can be considered to generate useful qualitative data for design guidance. The results of the quantitative and qualitative data analysis should be documented with the evaluation maneuver so that other users of the maneuver will know what type of data they can anticipate to gather with the maneuver.

1. How well does the maneuver represent the operational task element?	5 4 3 2 1 Closely ☐ ☐ ☐ ☐ ☐ Remotely
2. Is the maneuver well defined? Please describe any specific techniques used.	5 4 3 2 1 Well Defined ☐ ☐ ☐ ☐ ☐ Poorly Defined
3. Is the maneuver repeatable and easy to fly?	5 4 3 2 1 Easy, Repeatable ☐ ☐ ☐ ☐ ☐ Difficult
4. Did variations in design parameters result in observable differences in response?	5 4 3 2 1 Very Significant ☐ ☐ ☐ ☐ ☐ Not Significantly Different
5. Would entry/exit conditions be difficult to establish during flight test?	5 4 3 2 1 Easy ☐ ☐ ☐ ☐ ☐ Impossible
6. What information is required (e.g. airspeed, bank angle, target aircraft, etc.)?	5 4 3 2 1 Conventional Information ☐ ☐ ☐ ☐ ☐ Highly Specialized Displays
7. Additional comments:	

Figure 15. Maneuver Summary Comment Card Used During Simulations

Potential human factors considerations can also be estimated at this time. Combinations of time history data analysis and responses to pilot questionnaires, such as shown in Figure 16, can be used to assess maneuvers that are potentially disorienting or have the potential for g Induced Loss Of Consciousness (GLOC). Mathematical models that predict the pilot's susceptibility to GLOC or spatial disorientation based on aircraft acceleration time history profiles can be used at this time to evaluate the maneuver. Potentially dangerous maneuvers should be noted at this time and either refined or carefully tested in a motion-base simulation or in flight.

PREFLIGHT QUESTIONNAIRE

1. How many hours of sleep did you get last night?

2. Your last meal prior to this flight was...(circle one)
   breakfast
   lunch
   dinner
   snack

   How long has it been since you ate the above meal?

3. Your health today: (circle one)
   Excellent - no health problems
   Fair - slight head cold/allergies
   Poor - severe head cold/flu

POSTFLIGHT QUESTIONNAIRE

1. Did you experience: During what part of the maneuver?
   A tumbling sensation?
   Lightheadedness?
   Motion sickness?
   Disorientation?
   Other?

2. Do you feel there is a potential for spatial disorientation during this maneuver?
   If yes, what aspect(s) of the maneuver contribute to this?

   If yes, do you feel that training could be done to minimize this potential?

Figure 16. Human Factors Questionnaire Used During the Simulations

All of the simulation data and analyses should be reviewed to determine the next action to be taken on the maneuver. As Figure 14 indicated, the maneuver can be accepted as ready for use, refined further during simulation, or discarded. An evaluation form such as was shown in Figure 13 can be used to help assess the overall quality of the maneuver to determine if it has been developed sufficiently. Additional simulation refinement of the maneuver may prove valuable if identified weaknesses can be corrected.

Maneuver Validation and Documentation

The maneuver can be used as a design and evaluation tool once the Maneuver Development and Refinement process is complete; however, additional validation and documentation of the maneuver is highly recommended. For instance, the range of applicability of the maneuver should be checked. This validation can be conducted by testing the maneuver with different aircraft to make sure that the maneuver is not unique to the aircraft that was used to develop it. The maneuver should be generic enough that it can be altered slightly for a specific aircraft or test. Also, analytical and subjective assessments of potential motion effects can be conducted, particularly if fixed-base simulation testing is utilized for the maneuver development. Maneuvers that exhibit potential warning signs may need additional testing in a motion-base simulator with appropriate dynamic capability.[13] And of course, the final validation of a maneuver comes through in-flight testing. Some of the initial STEMS maneuvers have been successfully tested as part of Air Force Test Pilot School projects[14,15] and efforts are being made to validate all the maneuvers through various flight test programs. Several issues can be more closely examined during a flight test validation program such as safety of flight issues, ability to set up and execute the maneuver, and data requirements for the maneuver.

Documentation of the final evaluation maneuver is critical to the usefulness of STEMS. Newly developed maneuvers should be sent to Wright Laboratory/FIGC_2 for inclusion into STEMS[3] so that it becomes a "living document." The intent is that STEMS will eventually serve as a comprehensive guide to evaluation maneuvers. Each evaluation maneuver should be documented on a standard form as schematically shown in Figure 17. Additional background information on the maneuver, lessons learned, and validation testing conducted with the maneuver can be included in narrative pages that accompany the maneuver description page. Also, an "electronic" appendix to the STEMS maneuver reference guide has been developed to include example trajectories for the maneuvers. These examples can be viewed on the AGILE-VU flight trajectory visualization program[16] to assist in visualization of the maneuver and how it is to be performed. The example AGILE-VU files are also being maintained and distributed from Wright Laboratory/FIGC_2.

The various sections of the maneuver description form document the reasons why the maneuver would be flown, what type of attributes it measures, what mission it is intended to represent, how to set up and fly the maneuver, guidelines on developing Cooper-Harper Rating performance criteria, important notes and comments about the maneuver, as well as potential variations to the maneuver. A narrative description also accompanies each maneuver to

document additional information not found on the brief maneuver description form. Maneuvers should be written somewhat generally so they can be tailored to suit specific test objectives. They also may be modified based on configuration dependent placards, safety of flight issues, or unique capabilities. Additionally, specific setups may need to be altered based on the test aircraft (and target aircraft, if one is called for) performance capabilities. The maneuver descriptions include representative test conditions such as airspeed, altitude, and Angle Of Attack (AOA), but the specific conditions to be tested are left to the evaluator. Multiple variations of the maneuver are also briefly described to show potentially useful alternative approaches such as testing throttle setting variations for configurations with thrust vectoring.

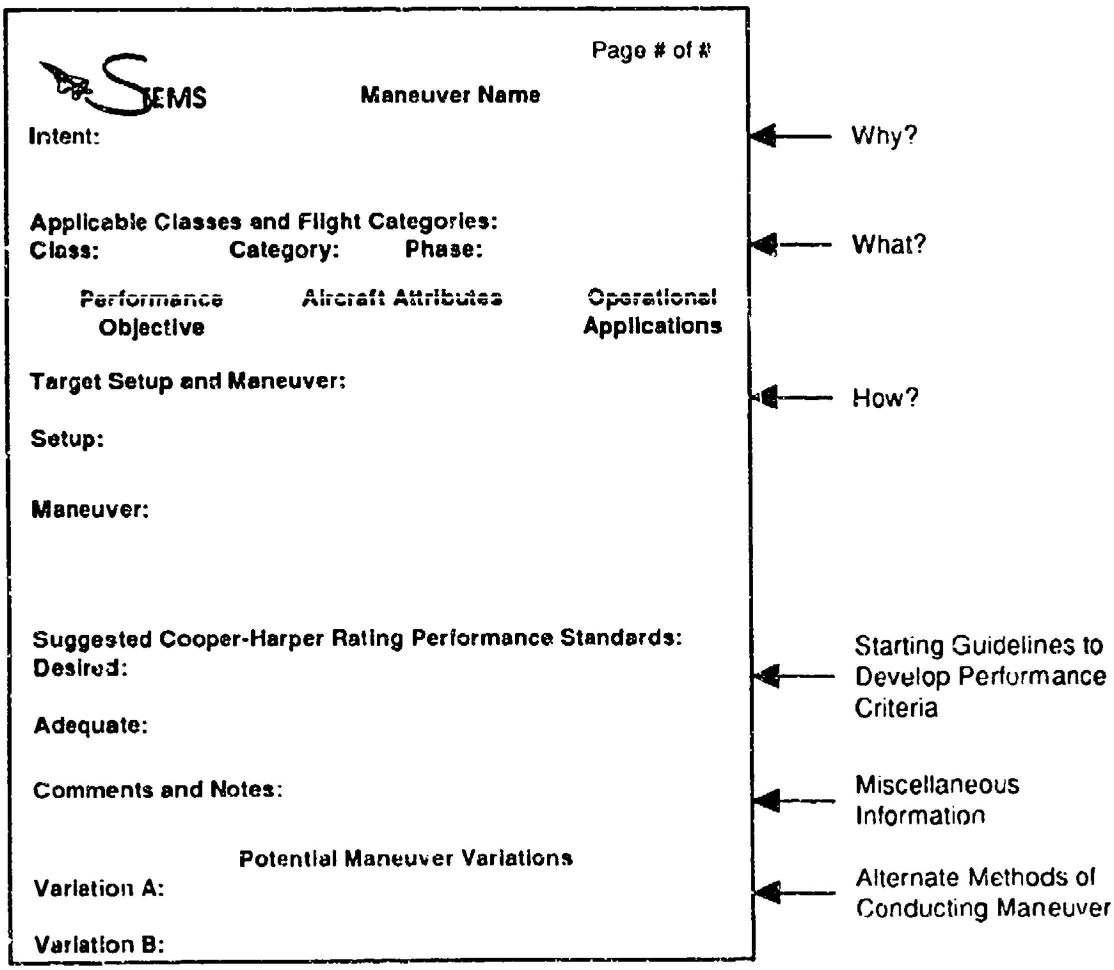


Figure 17. Maneuver Description Form

Maneuver Development Lessons Learned

Several valuable lessons were learned while evolving the maneuver development process described above. Some of these lessons will be summarized here to improve the quality of new evaluation maneuvers and minimize the time required to develop them. First, it was extremely beneficial to include both pilots and engineers throughout the maneuver development and analysis process. Second, it was valuable to include pilots with operational as well as test experience. Third, it is critical to evaluate the quality of data obtained from a maneuver prior to using it for the evaluation of an aircraft design. Fourth, it was found that piloted flight simulation could be used to efficiently and effectively develop maneuvers. Finally, DOE test techniques were used extensively during this research and some observations and considerations are summarized in this chapter.

Pilot and Engineer Involvement

It is recommended that both pilots and engineers be involved throughout the development of new evaluation maneuvers. It is also advantageous to include more than one pilot and more than one engineer to benefit from additional viewpoints and experiences. There may be some overlap and blend of knowledge between the pilots and engineers, but each tends to have a specialized background that can improve the value of the maneuver. In general, engineers were needed to determine the constraints on the maneuver and the data obtained from the maneuver. They could identify the type of data needed for design guidance such as single-axis flying qualities information, control harmony evaluations, maximum performance measurements, control margin validations, departure resistance testing, and others. They also suggested constraints on how the data should be generated such as requiring full stick inputs for maximum performance or allowing "freestyle" pilot inputs. Engineers also defined the important parameters for the initial conditions such as requiring an initially stabilized AOA, zero pitch rate, or a constant g turn. The pilots were invaluable in maintaining operationally representative conditions and defining techniques for the maneuvers. They also had important suggestions which improved the flyability and repeatability of the maneuvers. Pilot experience was important in identifying critical mission segments and modifying the maneuvers to better represent those conditions.

Benefits of Operational and Test Experience

The influence of pilots with operational and test experience on the maneuver development process is also important. The operational experience is important because of the desire to link these evaluation maneuvers to operational requirements. Pilots with operational experience have a good understanding of how the aircraft will really be used in training and operation and have experience in tactics and techniques. Flight test experience is also important to increase the overall quality of the maneuver and data acquired from it. Flight test skills help provide insight as to how to improve the maneuver setups and execution for better repeatability and data quality. Pilots with flight test backgrounds also have a better awareness of safety-of-flight issues for maneuvers that are intended to be used during flight test. And finally, flight test pilots can help the maneuver development process because they also tend to have a good understanding of flight dynamics and the Cooper-Harper Rating process.

During this research, both "test" and "operational" pilots were included to be sure to include both specialties. It was found that only one operational pilot and one test pilot were needed at any one time to support the maneuver development and data gathering process. In actuality many pilots, including those participating in this study, have a good blend of both skills. As a result, it may be beneficial to have both an "operational" and a "test" pilot involved, but having separate "test" and "operational" pilots may not be necessary if the pilots involved have a good blend of experience.

Data Quality Review

The final key element in defining maneuvers for design is the requirement for a maneuver review process. It is important to review the data generated from a maneuver and have an understanding of its sensitivity to design parameter variations before using it. It may be misleading to develop a maneuver with a single set of aircraft dynamics and then use it to evaluate design modifications or other aircraft. The data repeatability must be checked to evaluate the amount of pilot variability expected in the data. The pilot variability should then be compared to the changes observed due to design parameter variations to determine which pieces of data can be used in the design process. This data review should be applied to both quantitative and qualitative data. This implies that data is required from at least two pilots before any strong conclusions can be made about the maneuver. The research conducted under this contract used a formal Review Team with a variety of backgrounds to judge the value of a maneuver. The Review Team approach was efficient for the simultaneous development of

several maneuvers; however, a much simplified review process could be used when developing a few maneuvers.

Use of Piloted Flight Simulation

Flight simulation was found to be an effective tool in the development and evaluation of the maneuvers. Different approaches and techniques to fly a maneuver could be tried quickly and eliminated from consideration by using flight simulation. Additionally, a quick appreciation could be gained for the type of data generated and the aircraft characteristics evaluated. The maneuver can then be refined, while still in simulation, to produce better quality data. The simulation effort under this research was divided into three simulation entries. This multiple simulation approach was valuable because it allowed for periods of data review between simulations. The maneuvers, and test techniques, could then be refined during the next simulation based on previous data.

The Phase I portion of this research was used to generate several concepts and potential evaluation maneuvers; however, no simulation was included. As a result, the maneuvers were not ready to be used. Effort was spent discussing and refining the maneuvers rather than developing them for use. In contrast, the Phase II simulations were found to be much more effective for exposing the advantages and disadvantages of a maneuver. Different approaches and techniques to fly a maneuver could be tried quickly and eliminated from consideration by using flight simulation. Additionally a quick appreciation could be gained for the type of data generated and the aircraft characteristics evaluated. The background work and preparations conducted during Phase I certainly aided maneuver development during the simulations but, in retrospect, more time should have been spent flying the maneuvers and less time should be spent discussing them.

Observations from DOE Testing

Many of the simulation test matrices used during this research were based on Design of Experiment techniques. Fractional factorial matrices were used to minimize the data requirements so that as many maneuvers as possible could be developed. The DOE techniques worked well for quantitative data, but it was difficult to analyze the qualitative data since multiple design parameters were being simultaneously varied. In general, the fractional factorial tests appear to be appropriate for maneuvers that generated numerical data that is amenable to statistical analyses, but they are not generally recommended for maneuvers

designed to gather pilot comments. Also, it can be difficult to efficiently expand testing after an initial data set is taken. Simple test matrices could be augmented to include additional design parameters, but more complex matrices could not be augmented. As a result, it is very valuable to perform a quick, qualitative check of the intended test matrix prior to gathering a complete data set. In general, the DOE techniques evaluated during this research can be valuable for a screening effort but do not appear to be appropriate for a criteria development effort.

Chapter 3
Simulation Setup and Test Techniques

The simulation hardware and aircraft models that were utilized during the three STEMS simulations are described in this chapter. Additional details on the test setup including the design parameters selected, the test matrix selection techniques used, and data gathering procedures utilized are also included.

Simulation Setup

All of the simulation testing was conducted in a fixed-base, 40 ft diameter simulation dome as shown schematically in Figure 18. This dome contains an F-15C cockpit and controllers including a conventional center stick with characteristics as shown in Figure 19. This crewstation was used for both fighter and transport aircraft testing. The only modification made when testing the transport aircraft was that the military power detente was removed from the throttle hardware so that the full throttle range could be used. The simulation setup utilized a General Electric Compuscene computer graphics imaging system for out-the-window visual displays. The Compuscene system used a scenery database that represented Edwards Air Force Base. A video projection system and model boxes were used to display F-15 targets for air-to-air tasks. Additionally, a Compuscene generated KC-10 model was used for the refueling probe tracking task. Standard F-15C Head-Up Display (HUD) hardware was used to display modified F-15E HUD symbology to the pilot as shown in Figure 20. Several of the features on the HUD could be altered to test various Cooper-Harper Rating performance criteria. The size and depression of the reticle could be altered easily, and horizontal and/or vertical error bars could be displayed to help the evaluation pilot concentrate on the errors in a single axis. For closed-loop tasks, shoot cue lights on the cockpit canopy bow were programmed to illuminate when the pilot had achieved a capture for the desired length of time. A dual processor Gould SEL computer was used to drive the simulation. The aircraft model and most crewstation input/output ran at a 60 Hz update rate. Some secondary displays were updated at a slower rate, but the primary displays and the controller inputs were sampled at 60 Hz. The total simulation time delay from pilot input to visual scene update was estimated to be between 94 msec and 111 msec for the simulation setup used in this testing.[17]

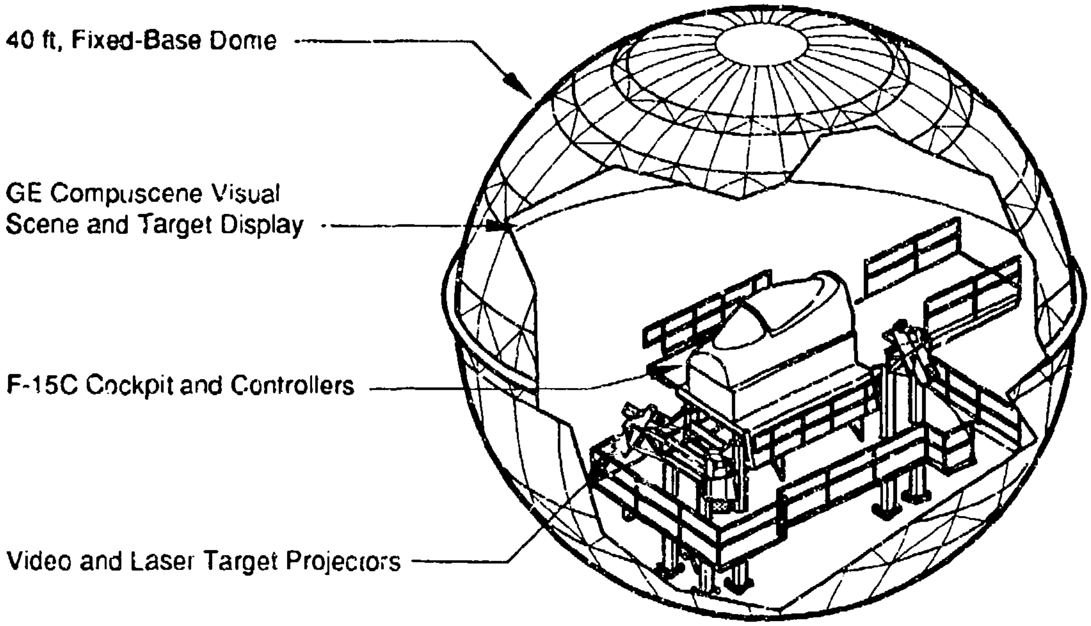
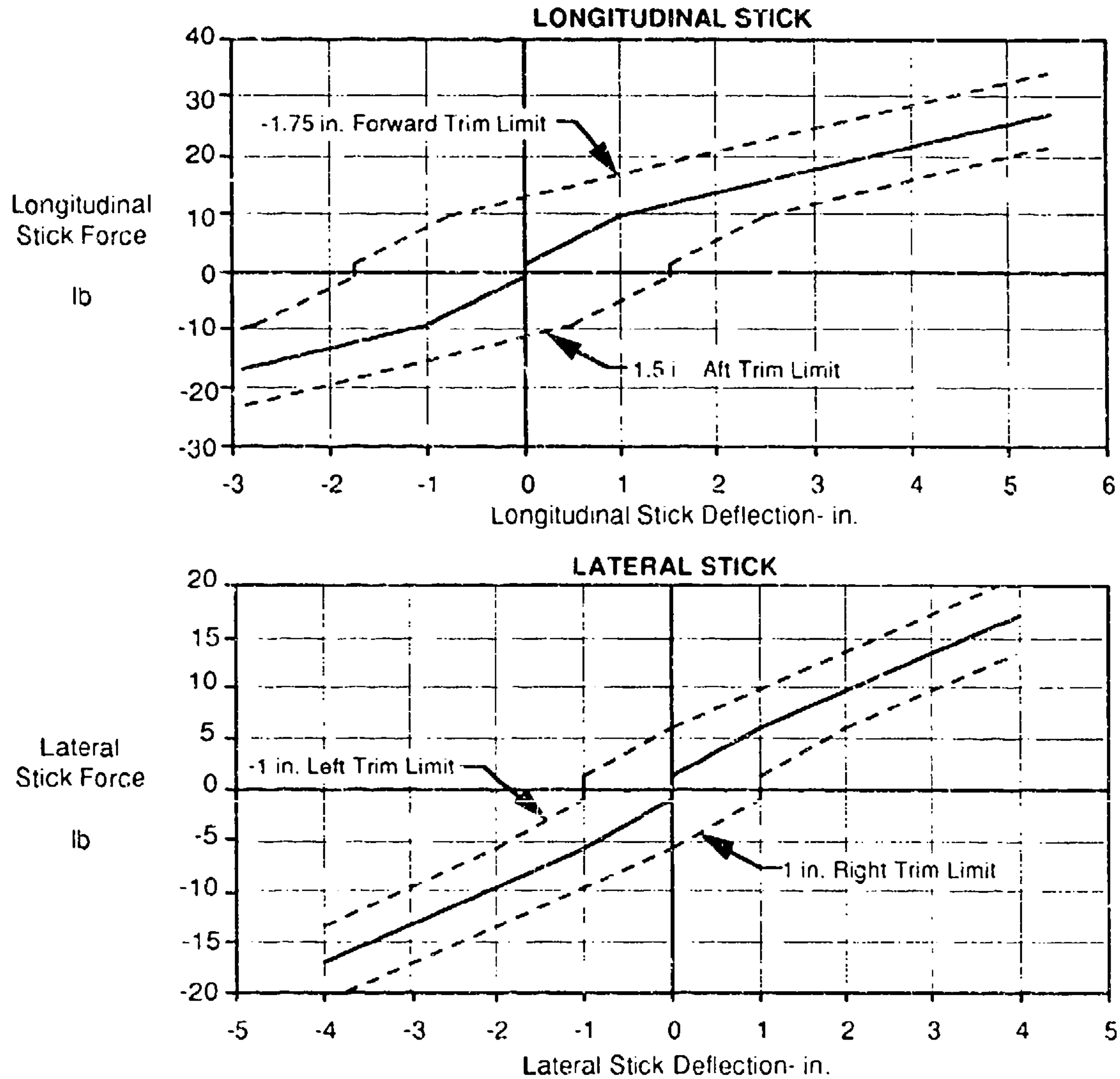


Figure 18. Simulation Dome Used for Testing

Three primary aircraft models were used during these simulations. Two models were simplified generic aircraft and the third was a complex, fully nonlinear aircraft model. The generic models represented a fighter aircraft and a transport aircraft. The generic fighter model was used for the majority of the maneuver development and design parameter testing. This model was based on the McDonnell Douglas Aerospace (MDA) Generic Aircraft (GENAIR) simulation tool. GENAIR provided the capability to vary the closed-loop aircraft characteristics easily and efficiently over a wide range while maintaining realistic nonlinear performance as illustrated in Figure 21. This simulation model has been used successfully in the past to develop high AOA maneuvers for flight test[18], to develop low and high AOA flying qualities criteria[19,20], and conduct agility evaluations[21]. The F-15 STOL and Maneuvering Technology Demonstrator (S/MTD) Multi-System Integrated Controls (MuSIC) aircraft model was used to validate the maneuvers developed with GENAIR. The MuSIC model is a complex, high-fidelity simulation model that includes a nonlinear database and a complete control system[22]. The MuSIC model was used to validate the flyability of the maneuvers with a complex model that had significantly different performance and flying qualities than the GENAIR model.



Axis	Gradient Type	Force Gradient	Breakout Force	Position Limits
Longitudinal	Dual	8.5 lb/in. (< 1 in.) 4.0 lb/in. (> 1 in.)	±1 lb	+5.4 in. -2.9 in.
Lateral	Dual	5.0 lb/in. (< 1 in.) 3.67 lb/in. (> 1 in.)	±1 lb	±4.0 in.
Directional	Single	45.0 lb/in.	±7.67 lb	±3.25 in.

Feel System Dynamics

$$\frac{\delta_{lon}}{F_{lon}} = \frac{1}{\left(\frac{S}{25.9}\right)^2 + \left(\frac{2\,(0.12)}{25.9}\right)S + 1}$$

$$\frac{\delta_{lat}}{F_{lat}} = \frac{1}{\left(\frac{S}{25.0}\right)^2 + \left(\frac{2\,(0.83)}{25.0}\right)S + 1}$$

Figure 19. Simulation Controller Characteristics

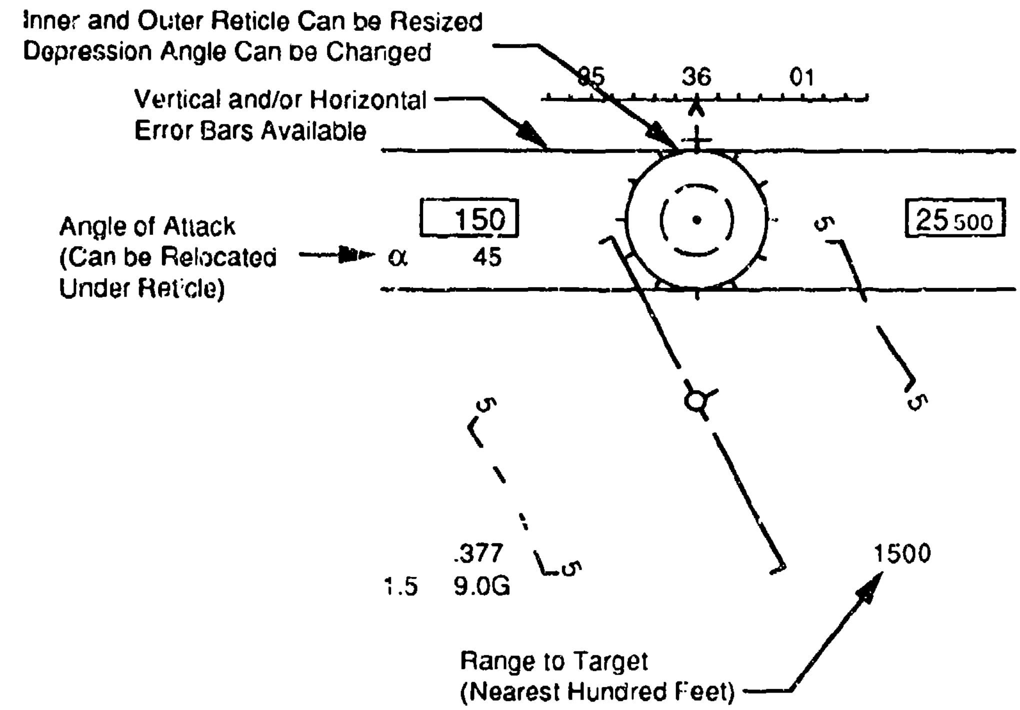


Figure 20. HUD Symbology Used During Simulation Testing

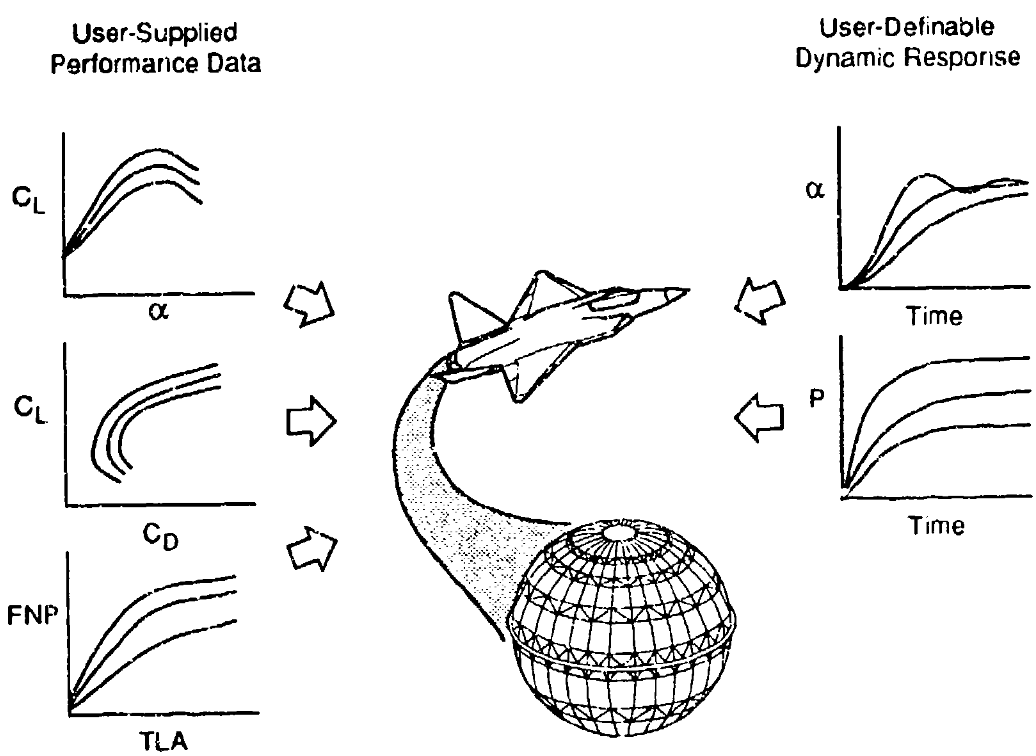


Figure 21. Variable Response Generic Aircraft Simulation Model

The generic fighter model was used for the majority of the testing. Its baseline performance was representative of a modern high-performance fighter aircraft; however, its dynamic response could be changed to test design parameter variations. The dynamic response was completely generic and varied widely during testing to emulate variations in closed-loop aircraft dynamics. The design parameters varied during these simulations are listed in Figure 22. The generic aircraft model could be used to vary many more design parameters than shown on this figure, but these were sufficient to evaluate the maneuvers developed in this research. Several longitudinal command types were used during the generic fighter testing. These included AOA command, AOA rate command, load factor command, and pitch rate command systems. Most of the testing was conducted with AOA and load factor command systems, but specific maneuvers were also validated with the rate command systems. A stability axis roll rate command system was implemented in the lateral axis so that the pilot commanded a coordinated roll through lateral stick inputs. A sideslip command system was implemented in the directional axis and a limited amount of roll rate resulted from rudder pedal inputs.

Abbreviation	Description
AOAMAX	Maximum AOA (low speed) and maximum load factor (high speed)
CAP	Control Anticipation Parameter (related to short period frequency)
CLMAX	Maximum lift coefficient
CMDTYP	Longitudinal command type: AOA, AOA rate, pitch rate, or load factor
DCG	Center of gravity location
LALPHA	Lift curve slope and pitch rate lead term
LATDYN	Combination of lateral dynamics (TR, PMAX, etc.)
LONDYN	Combination of longitudinal dynamics (CAP, ZSP, AOAMAX, LONSHP, etc.)
LONSHP	Whether or not nonlinear longitudinal stick shaping was used
LONSNS	Longitudinal stick sensitivity
MALPHA	Longitudinal stability
PMAX	Maximum attainable stability axis roll rate
PDLIM	Roll acceleration limiter
TAUENG	Engine time constant
TIMDEL	Pure time delay added to the simulation (in addition to inherent time delay)
TR	Roll mode time constant
TV	Whether or not thrust vectoring was used
TW	Multiplier on the baseline thrust-to-weight ratio
ZSP	Short period damping
ZW	Inverse of the pitch rate time constant for first-order pitch rate command
WSP	Short period frequency

Figure 22. Design Parameters Varied During the Generic Fighter Testing

The generic transport model was used for a minimal amount testing to determine if the STEMS maneuvers could be applied to aircraft other than fighters. The baseline performance and dynamics of this model were representative of a responsive powered-lift transport aircraft. However, the dynamic response of the transport model was varied during the simulation

testing. Figure 23 shows the design parameters that were varied during the transport maneuvers. This is a much abbreviated list compared to the design parameters varied during the fighter testing because of the limited amount of simulation time devoted to transport testing. An AOA command system was implemented in the longitudinal axis; a roll rate command system was used in the lateral axis; and a sideslip command system was implemented in the directional axis.

Abbreviation	Description
CAP	Control Anticipation Parameter (related to short period frequency)
PMAX	Maximum attainable stability axis roll rate
TR	Roll mode time constant
ZSP	Short period damping
WSP	Short period frequency

Figure 23. Design Parameters Varied During the Generic Transport Testing

The MuSIC aircraft model was used for a majority of the maneuver validation and for some design parameter variation testing. This model is a built upon the F-15 S/MTD database with modifications that represent the addition of axisymmetric pitch and yaw vectoring nozzles. The MuSIC aircraft model, Figure 24, was developed under another effort to investigate the tactical utility of pitch and yaw vectoring during air combat engagements[22]. That study resulted in the development of new high AOA fighter tactics[23]. Some of these tactics were incorporated into the maneuvers developed during the STEMS research. The MuSIC aircraft was flown in two modes: Post-Stall (PST) on and PST off. When PST is engaged, the MuSIC aircraft is an extremely agile configuration with essentially no AOA limit and very good high AOA roll authority. When PST is off, the MuSIC model has greatly reduced roll authority at moderate to high AOA and can only reach approximately 40° AOA. The variation between PST on and PST off was used as an additional evaluation for some of the STEMS maneuvers. The MuSIC model was also flown in conjunction with the Fighter Airframe Propulsion Integration Predesign (FAPIP) program.[24] During this testing, STEMS maneuvers were used to evaluate nozzle design variations including maximum nozzle rate capabilities and various nozzle time delays. This provided further validation of the ability to use STEMS maneuvers during the design process.

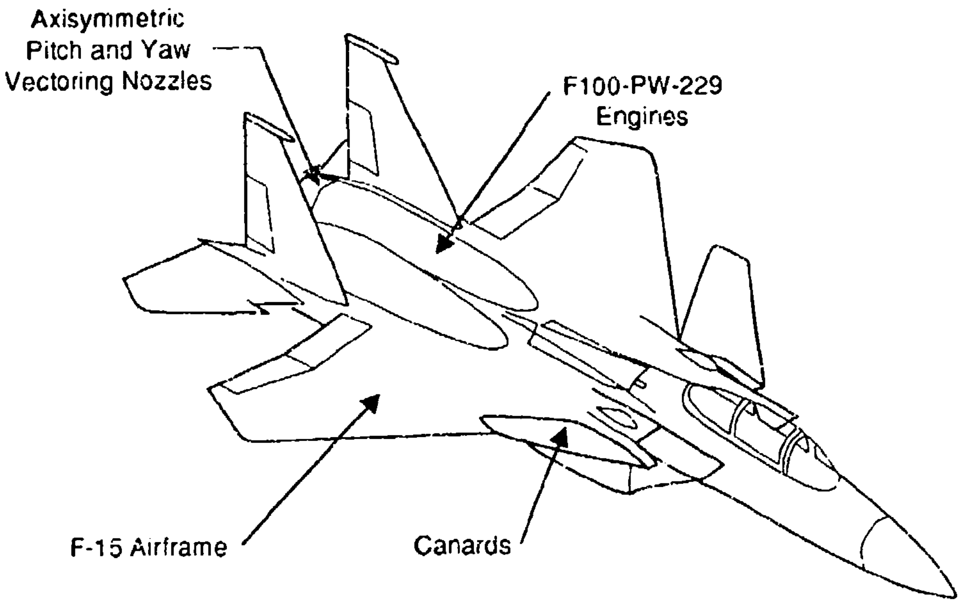


Figure 24. F-15 S/MTD Multi-System Integrated Controls (MuSIC) Model

Design Parameter Selection

A primary objective of this research was to tie evaluation maneuvers to the design process so that they can be used to improve a design prior to flight test or operational use. To verify this link, design parameters were varied during the simulations and data was gathered to evaluate the ability to use a maneuver during the design process. High-level, augmented design parameters were used during this testing to maintain generic results rather than configuration dependent trends. In other words, design parameters such as augmented short period frequency were tested rather than static margin, pitch control power, and control system gains. The augmented (aircraft plus control system, closed-loop dynamics) design parameters tested were similar to those resulting from an equivalent system analysis.[25] The justification of this test approach lies in the fact that with modern control systems, the pilot is evaluating the overall system response instead of basic stability derivatives and bare airframe response. The achievable aircraft dynamics depend upon several basic parameters such as the center of gravity location, wing design, leading edge extension shape, and available control powers. However, the trade-offs between these basic design considerations and the achievable dynamics is very configuration dependent and beyond the scope of this study. Additionally, depending upon the control powers available, a wide range of dynamic responses can be achieved.[26] As a result, variations in bare airframe design parameters were not tested. Instead, equivalent system type

parameters were varied to establish if a maneuver could be used to uncover design deficiencies that affect the pilot's ability to complete the mission or task.

The particular design parameters selected for testing and the ranges over which they were varied depended upon the maneuver. Only a few parameters could be tested for each maneuver because of the number of maneuvers being developed. It was believed to be sufficient to establish a sensitivity to two or three design parameters for a particular maneuver. The Review Team identified a potential list of design parameters for each maneuver during Phase I. Engineering judgment was then used to select a few of the most likely parameters to affect each maneuver. The range for each design parameter was based on existing criteria, recent research, and/or engineering judgment. An attempt was made to select large enough ranges such that a good maneuver would show a difference between configurations. For example, short period frequency might be varied between a MIL-STD-1797A Level 1 value to a Level 2 value.[9] The design parameters being tested for a particular maneuver were sometimes changed between simulations if the simulation data analysis showed little or no effect due to a design parameter. A new range of variation was tested if the Review Team suggested that the original range was too small or too large.

Design of Experiment Test Approach

A Design Of Experiments[10] test approach was used during simulations to test the sensitivity of the maneuver to design parameter variations. This statistically-based test approach allows several design parameters to be tested with a minimal number of configurations. Post-simulation data analysis then relies on statistical techniques to isolate the effects of each design parameter on the data being evaluated. These statistical analyses were conducted for each candidate measure of merit for each maneuver. The outcome of the statistical tests indicates the change in the measure of merit that is due to each design parameter and provides a measure of statistical confidence in the answer. These analyses also provide an indication of the amount of pilot variability in the simulation data.

The DOE test technique was adopted as a design parameter screening approach for the maneuver development process. During the maneuver development, it was necessary to test each maneuver's sensitivity to several design parameters. An efficient technique was needed to help identify which design parameters could be used to alter the performance of the aircraft during that particular maneuver. The DOE approach enables the use of much smaller test matrices -- typically half the size of standard tests or even smaller. These reduced matrices

were sufficient to establish sensitivities, but may not have been thorough enough to define criteria boundaries or establish recommended values for individual design parameters. However, this research was not intended to be a criteria development effort.

The DOE techniques require specific test matrices be used so that the statistical analyses can be conducted properly. A variety of test matrices have been designed and can be selected depending on the number of parameters that the researcher is investigating.[10] The test matrix most commonly used during this maneuver development research allowed three design parameters to be tested at two values each while requiring only four configurations. If all possible combinations were tested, then eight configurations, and therefore twice the data, would have been required. The DOE test matrix is also referred to as a fractional factorial as opposed to a full factorial matrix (all combinations tested). Another test approach could have been used in which one configuration would have been selected as a baseline and then each of the three design parameters could have been individually varied to generate a total of four configurations. It was reasoned that this approach would result in a more "local" indicator of trends, whereas the DOE approach would measure more of a "global" sensitivity and would allow more comprehensive statistical tests. The specific combinations of design parameter values that needed to be tested, according to DOE guidelines, are shown in Figure 25 for a three factor (design parameter) test. Statistical analyses can be conducted to isolate design parameters A, B, and C if data is available for the four highlighted configurations. These statistical tests indicate the difference in average measure of merit values between faces of the test cube as diagrammed on the lower portion of this figure. Larger test matrices were also used that allowed as many as seven design parameters to be evaluated while using only eight test configurations. Figure 26 summarizes the three DOE test matrices used during this study. The positive (+) and negative (-) signs indicate the two values for each design parameter.

The DOE techniques had advantages and disadvantages for this particular application. These matrices required fewer configurations to be tested when several design parameters were being evaluated; therefore, it allowed more maneuvers to be developed in the limited amount of time available. It worked favorably for the numerical analysis of measure of merit data but it made the qualitative analysis more difficult and less conclusive. The numerical analysis was simplified because standard statistical techniques could be applied to process the data However, qualitative data analysis is usually performed by making comparisons between configurations where only one design parameter is being altered. Unfortunately, the statistical techniques used to process the numerical data could not be used on pilot comments. As a result, it was difficult for the Review Team to isolate the effects of a single design parameter

because when they compared pilot comments between configurations there were always at least two design parameters varying. This made it difficult to determine which comments should be attributed to which design parameters. For example, some similar deficiencies may be observed when comparing a configuration with a low short period frequency and low damping to a configuration with high short period frequency and high damping. Some comments may be traced directly to a single design parameter, but others are hard to identify because both a low frequency and a high damping have the effect of slowing the aircraft response to pilot input. The qualitative data analysis became increasingly difficult as the number of design parameters was increased. The seven design parameter matrix shown in Figure 26 was poorly suited for the review of pilot comments because so many parameters were being varied simultaneously.

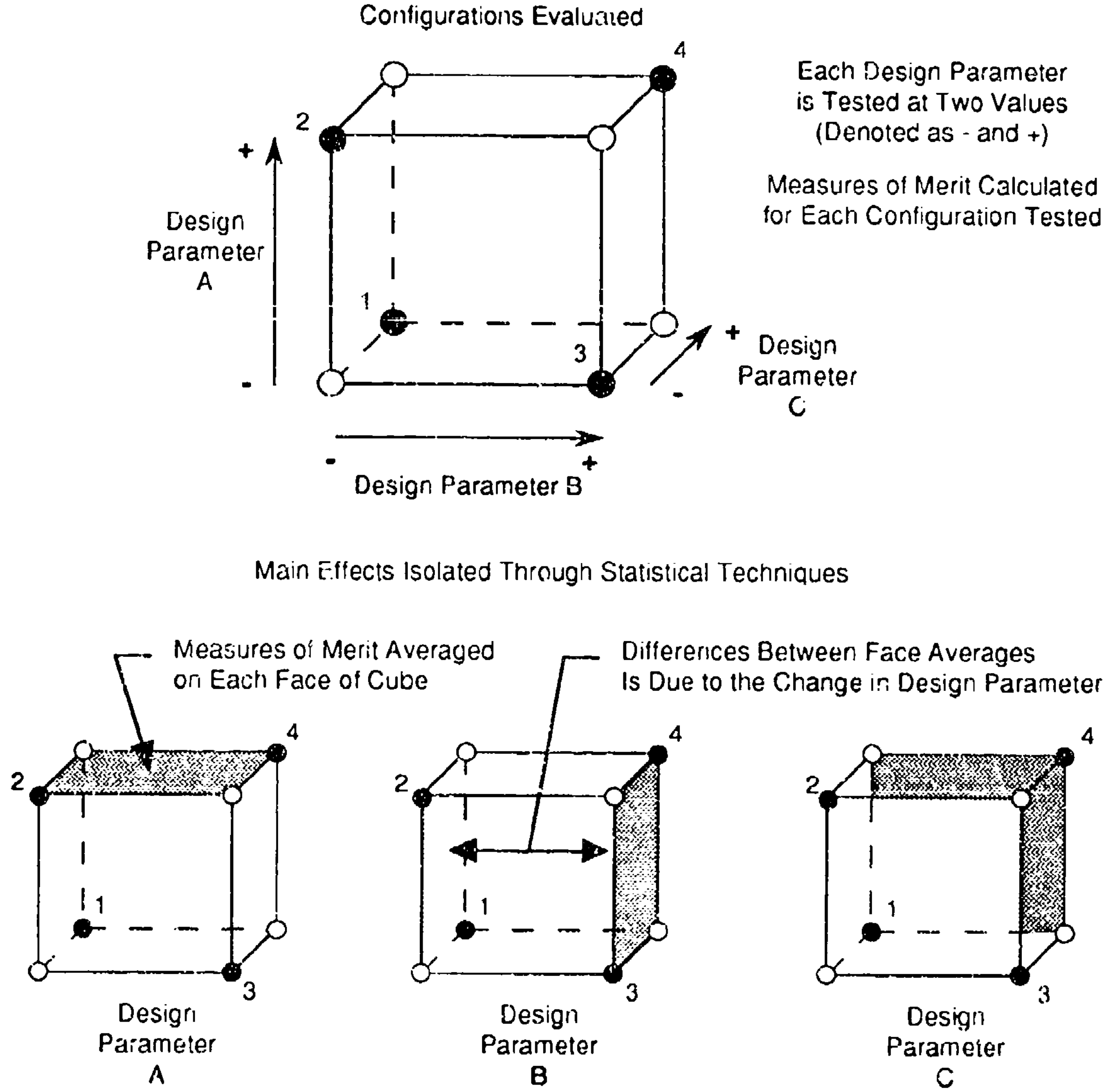


Figure 25. Fractional Factorial Approach Used to Screen Design Parameters

Config	Design Param A	B	C
1	-	-	+
2	+	-	-
3	-	+	-
4	+	+	+

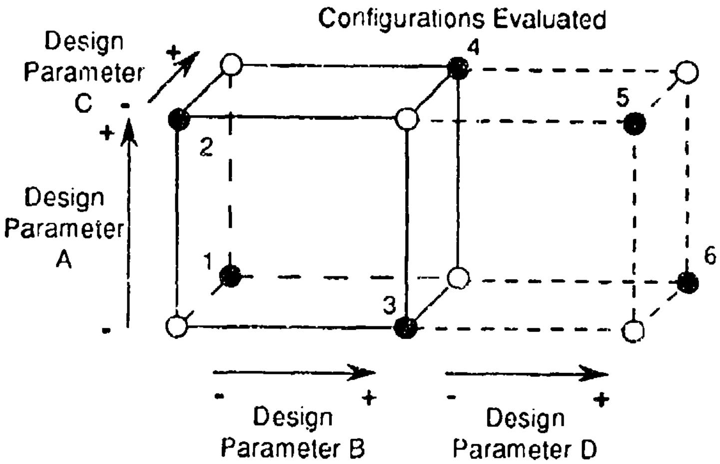
(Note: Same Matrix as Described in Figure 25)

Config	Design Param A	B	C	D
1	-	-	-	-
2	+	-	-	+
3	-	+	-	+
4	+	+	-	-
5	-	-	+	+
6	+	-	+	-
7	-	+	+	-
8	+	+	+	+

Config	Design Parameters A	B	C	D	E	F	G
1	-	-	-	+	+	+	-
2	+	-	-	-	-	+	+
3	-	+	-	-	+	-	+
4	+	+	-	+	-	-	-
5	-	-	+	+	-	-	+
6	+	-	+	-	+	-	-
7	-	+	+	-	-	+	-
8	+	+	+	+	+	+	+

Figure 26. Design of Experiments Test Matrices Used During Simulations

It was also somewhat difficult to add new parameters to a DOE test matrix during a simulation or between simulations. Post-simulation statistical analysis must be conducted before any results can be obtained; consequently, results obtained during a simulation cannot be used to alter the test matrix during that simulation. Therefore, it is valuable to perform a quick qualitative evaluation of the test matrix to help refine it prior to collecting data. Some DOE test matrices were successfully augmented to add an additional design parameter after data had been acquired, but in other cases an entirely new test matrix was required. The simple three factor test matrix described in Figure 25 was easy to augment with additional design parameters as shown in Figure 27. Unfortunately this technique did not allow a direct statistical comparison between all four design parameters shown on this figure, but it did allow previously collected data to be the reused. The larger, more complex DOE matrices were difficult or impossible to augment in a similar manner. So, a completely new matrix was tested if a change was required between simulations.



Original Test

Config	Design Param A	B	C
1	-	-	+
2	+	-	-
3	-	+	-
4	+	+	+

Additional Test

Config	Design Param A	C	D
3	-	-	-
5	+	-	+
6	-	+	+
4	+	+	-

Figure 27. Three Factor DOE Matrix Augmented for Additional Parameters

Care must be used when choosing the design parameters and matrix for DOE testing. In particular, the test factors should be "orthogonal" (not dependent upon any other test factor) and cannot be "confounded" (interdependent) for the statistical techniques to be valid. This was inadvertently violated with a test matrix during the first simulation. Three design variations were conducted during this test. Short period frequency, short period damping, and nonlinear longitudinal command shaping were tested. Unfortunately, the longitudinal command shaping was implemented by a method that resulted in confounding, therefore voiding the results. The command shaping was used to provide a fast response when a large difference between the commanded and actual AOA existed, and it slowed the response for small stick inputs. It was implemented by scheduling short period frequency and damping with the command error so that both a desired acquisition and a desired tracking response could be obtained. However, the statistical analyses were invalid because of the interdependencies among command shaping, short period frequency, and short period damping.

The statistics associated with this DOE process were valuable to those with experience or a background in statistics, but were confusing to other members of the Review Team. The Review Team members had mixed success interpreting the raw statistical data because of their varying levels of statistical training. Those members with good statistical backgrounds were able to interpret the raw statistics effectively. Other Review Team members had much better results in reviewing processed, summary statistical information. The final format used to summarize the statistics will be discussed briefly in Chapter 5 and more fully detailed in Reference 4.

Data Taking Procedures

A set of well-defined data gathering procedures was followed during the simulations to ensure consistent data quality. Guidelines, such as the number of pilots who evaluated the test matrices, the number of repeats flown, and the methods used to conduct Cooper-Harper Rating evaluations were established during the first simulation. It was especially important to follow consistent data gathering procedures for the data that was to be statistically processed. Data was gathered from a minimum of two pilots so that the potential for pilot variability could be studied. When possible, testing was conducted so that data from one test pilot and one operational pilot would be available for analysis. This helped maximize the type and variety of comments and evaluations available from a maneuver. In the end, it is believed to be important to include data from a test pilot and an operational pilot, but this may not be necessary if the

pilots participating have a broad range of experience. Data was gathered from four pilots in a few maneuvers to investigate pilot variability further.

Each pilot flew the maneuver with a set of baseline dynamics until he was familiar with the setup and any specific techniques required. Next the pilot was given a set of dynamics for evaluation. He flew the configuration until he had established a relatively consistent, comfortable, and operationally representative technique. Three data runs were then recorded for post-simulation analysis. Additional data runs would have been beneficial, but only three were used to minimize the time required and amount of data processing needed for each maneuver.

Pilot comments were continuously recorded during the simulations. The comments were transcribed after the simulations and were edited for clarity and brevity. The resulting pilot comments have been sorted by maneuver and configuration and are included in Reference 4. These comments were important to help evaluate the qualitative data generated from each maneuver. In particular, the pilots were asked to comment on the configuration response and their ability to perform the task. A simulation comment card was completed by the pilots after completing all of the configuration evaluations. This questionnaire was intended to capture the pilot's overall opinion of the maneuver. The final questionnaire was shown in Chapter 2, Figure 15. The pilots completed written comment cards during the first simulation and verbal comments were recorded during the second and third simulations. Many more comments were received verbally than written.

Pilot ratings were completed only for appropriate maneuvers. The Cooper-Harper[8] and PIO[9] rating scales were used to evaluate configurations during flying qualities tasks. The Cooper-Harper Rating scale is shown in Figure 28 and the PIO rating scale is shown in Figure 29. Ratings were only completed by pilots who had been trained in the use of flying qualities scales. The Cooper-Harper and PIO ratings were completed using a multi-function display in the cockpit. This display includes an electronic implementation of Cooper-Harper Rating decision tree that is used to emphasize the decision tree process and descriptive words rather than actual numerical ratings.[27] The value of pilot comments to support and describe the pilot rating was stressed during the simulations. Additionally, a "long-look" evaluation technique was used to allow the pilot adequate time and plenty of evaluations prior to completing the rating.[28,29]

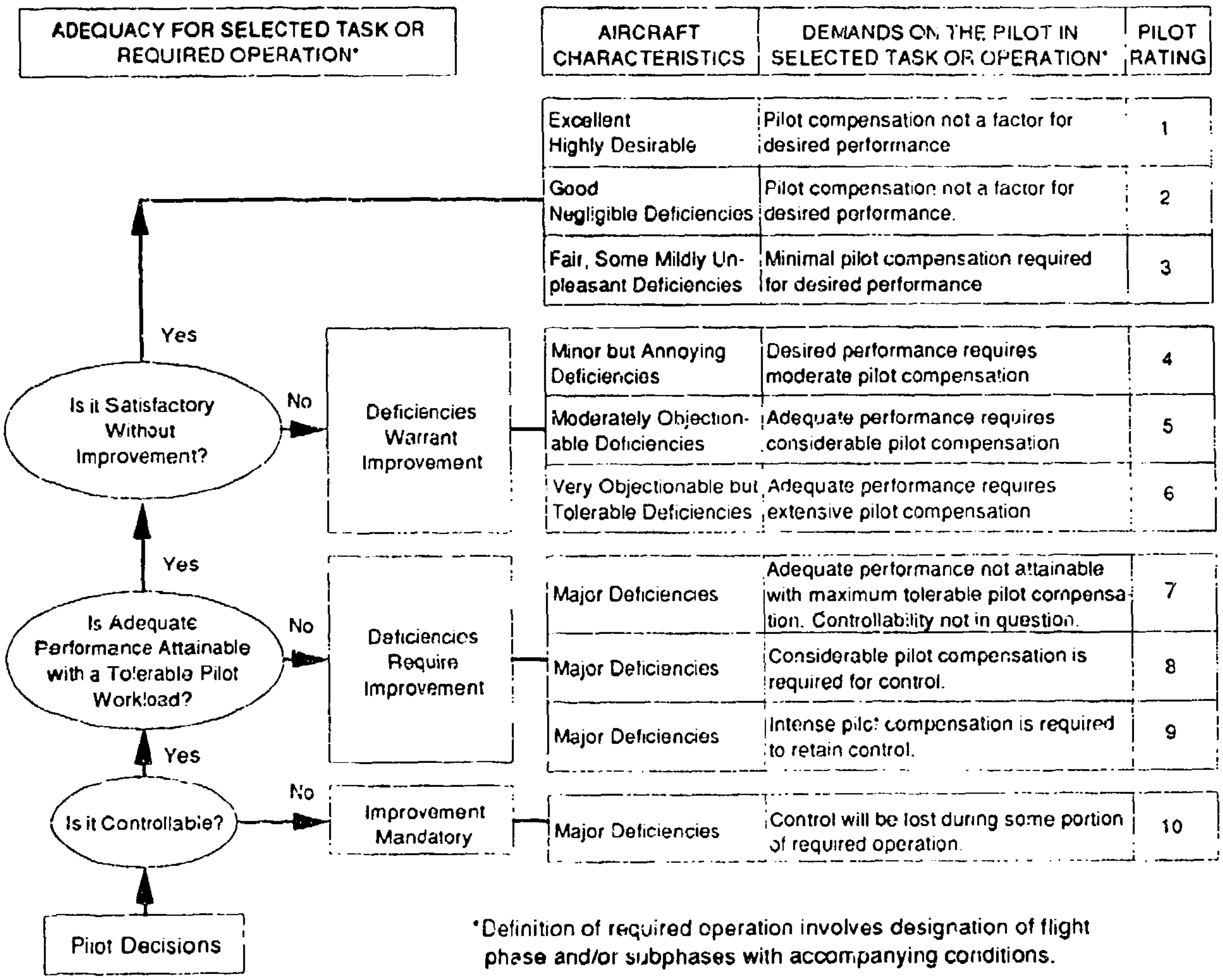


Figure 28. Cooper-Harper Rating Scale

A new, NASA/Navy developed Pitch Recovery Rating (PRR) scale was also used during this testing.[12,30] This scale is shown in Figure 30 and is structured similar to the Cooper-Harper rating scale but is specialized for the evaluation of nose-down pitch authority. This scale was only used for the 1-g stabilized pushover maneuver that was developed in Reference 30. Also, this scale was used by the single participating pilot who was trained to use it.

Time history data was stored to magnetic tapes during the simulation. All of the basic aircraft states, pilot inputs, and important internal simulation code parameters were saved for future use. All of the runs were saved to tape, but only the "data" runs, as described above, were later retrieved for post-simulation data analysis. Additionally, audio and video recording were conducted during all simulations. The video tape was used to record the HUD image, the target (when in the HUD field-of-view), and a display of the pilot inputs.

Description	Numerical Rating
No tendency for pilot to induce undesirable motions.	1
Undesirable motions tend to occur when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique.	2
Undesirable motions easily induced when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort.	3
Oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must reduce gain or abandon task to recover.	4
Divergent oscillations tend to develop when pilot initiates abrupt maneuvers or attempts tight control. Pilot must open loop by releasing or freezing the stick.	5
Disturbance or normal pilot control may cause divergent oscillations. Pilot must open control loop by releasing or freezing the stick.	6

Figure 29. Pilot Induced Oscillation Rating Scale

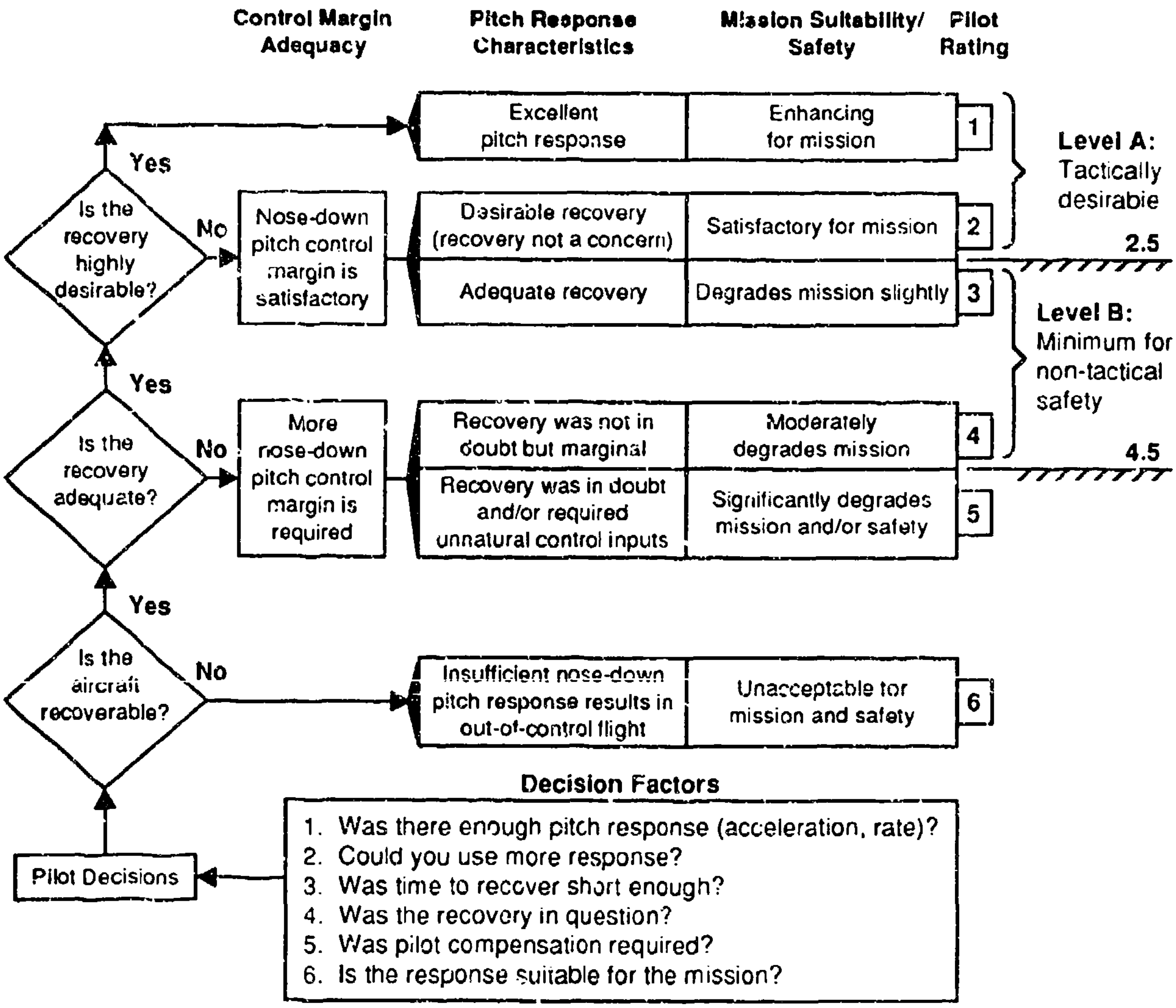


Figure 30. Pitch Recovery Rating Scale

Chapter 4
Evolution of Maneuver Development Process and Maneuvers

A maneuver development process and new evaluation maneuvers were defined during this research. The final recommended maneuver development process is described in Chapter 2 and the maneuvers are described in Chapter 5 and Reference 3. This chapter provides additional information that describes how the maneuver development process was used and refined while developing new evaluation maneuvers. The information in this chapter will be presented in an order that parallels the steps in the maneuver development process and follows the work conducted in a chronological order.

Candidate Maneuver Definition and Screening

The first step of the maneuver development process, Candidate Maneuver Definition and Screening, was conducted during Phase I of this contract. Phase I was used to generate a wide range of potential evaluation maneuvers and then sort out the most promising maneuvers for later refinement and testing during Phase II. An overview of the Phase I process is shown in Figure 31.

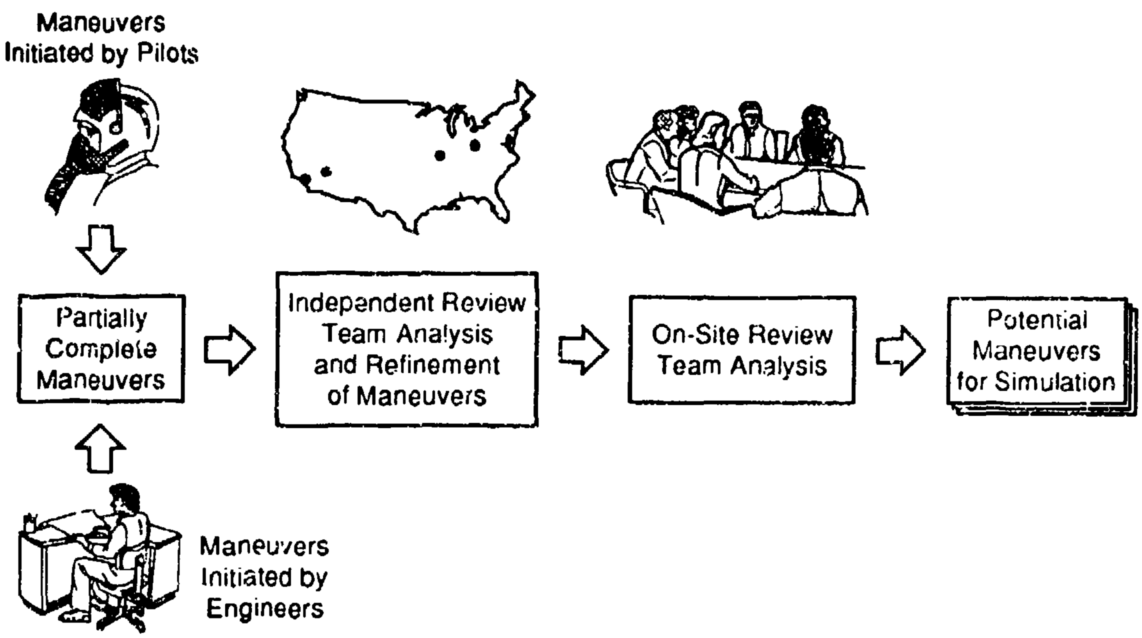


Figure 31. Phase I Generated a Large Database of Potential Maneuvers

A "brainstorming" approach was used to develop a wide selection of potential maneuvers. During this step, pilots and engineers independently identified potential maneuvers based on their experiences. They submitted their suggested maneuvers on a maneuver description form like that shown in Figure 32. The pilots and engineers were asked to complete only the sections of the maneuver description form that applied to their backgrounds. The form was designed to have pilots suggest maneuvers based on operational tasks and concentrate on the right-hand sections of the form. As a result, pilots identified operational scenarios that they had experienced or observed during missions or training exercises. They also suggested operationally meaningful measures of merit and performance attributes that could be associated with each potential maneuver. The engineers identified maneuvers that they thought would isolate design parameters and be useful for design guidance. The engineers then continued to complete the form from left to right as their backgrounds allowed. Additionally a literature search was conducted to find existing documented maneuvers. The literature search revealed several valuable maneuvers but also substantiated the need for a uniform method of documenting and describing evaluation maneuvers.

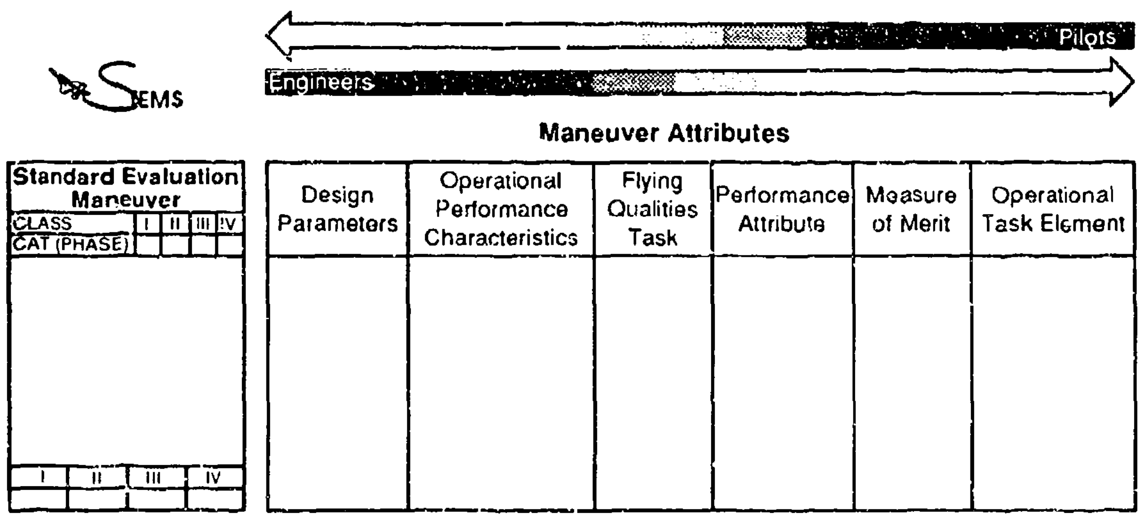


Figure 32. Original Version of the Maneuver Description Sheet

This first step in the Candidate Maneuver Definition and Screening phase resulted in 294 candidate maneuvers. They ranged widely in complexity from very simple to very complex maneuvers, and several aircraft classes and flight categories were represented. The maneuver descriptions were not complete because, as described above, the Review Team worked independently and only completed the sections of the maneuver description form that their background allowed. As a result, the maneuvers submitted by pilots tended to have information in the right-hand columns while the engineers' maneuvers tended to be complete

on the left-hand side of the form shown in Figure 32. At this point, the maneuvers were studied and combined because several very similar maneuvers were submitted. In some cases, the pilots' inputs were merged with the engineers' inputs to form a more complete maneuver description. This compilation resulted in approximately 200 unique potential maneuvers.

Of these 200 maneuvers, a few basic maneuver components recurred repeatedly. For example, simple maneuver segments such as roll and capture, pitch and capture, level turn, or axial acceleration maneuvers could be broken out of larger more complex maneuvers. However, some complex maneuvers could not be broken down into smaller maneuver elements. These observations led to classification of maneuvers into one of the three following categories: individual maneuvers, maneuver sequences, and freestyle maneuvers as shown in Figure 33. Individual maneuvers were defined to be the most basic element of a maneuver and could not be broken down further. Examples of individual maneuvers include the following: full stick pitch pull, nose-high pushover, and a 360° roll with no capture required. Maneuver sequences can be visualized as combinations of individual maneuvers. A pop-up ground attack maneuver can be thought of as a maneuver sequence because the pilot pulls to a desired pitch attitude, climbs to a given altitude, rolls inverted, pulls to and captures a target, then rolls back to wings level while tracking the target. And as the name implies, freestyle maneuvers allow the pilot a great deal of freedom to fly the maneuver. Basically only the start condition and end condition are specified for a freestyle maneuver. The pilot has the freedom to maneuver in any method to transition from one state to the other state. An example freestyle maneuver would be a minimum time 180° heading change where the pilot was allowed to try a variety of tactics. It was determined later in this research that not all maneuvers could be rigidly categorized as a certain type of maneuver, but these definitions are helpful to loosely describe the maneuvers.

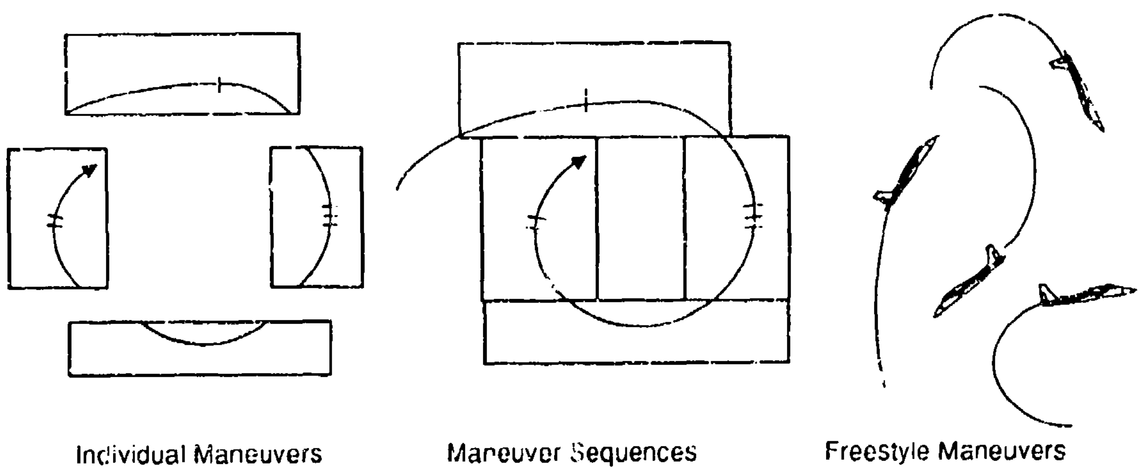


Figure 33. Maneuvers Can Generally Be Classified Into Three Categories

The next step in Phase I consisted of an independent review of all of the maneuvers by the Review Team. This is the first time that Review Team members were able to review candidate maneuvers recommended by other team members. Many of the maneuvers had been merged together and the maneuver description forms were more complete; however, some blank columns still remained. The Review Team members were asked to comment on the maneuvers and fill in any remaining blanks that they could. During this process, engineers were able to complete maneuvers initiated by pilots and vice versa. Review Team members also recommended the elimination of many maneuvers. Several reasons were used to eliminate maneuvers including the following: commonly accepted maneuvers were removed because of the desire to augment existing evaluation maneuvers, maneuvers that were not dominated by flying qualities or agility attributes were deleted, maneuvers that only isolated deficiencies already exposed by other maneuvers were eliminated, maneuvers that appeared to be overly complex to set up and fly, and maneuvers that were not demanding enough to uncover deficiencies were dropped from consideration. This screening process reduced the number of potential maneuvers to 89. At this point, the Review Team independently voted for the maneuvers they thought were the most important to continue developing. The results of this voting were used to select the top 32 candidates for future consideration.

After selecting the top 32 potential maneuvers, an on-site Review Team meeting was held to discuss and further develop these candidates. This step represented the first time that a joint Review Team analysis of the maneuvers was conducted. All of the 32 maneuvers were reviewed and the two-day meeting resulted in the refinement of 17 maneuvers, the elimination of 15, and the identification of 8 new potential maneuvers. Figure 34 lists each group of maneuvers, reasons for eliminating maneuvers, and documents which maneuvers were successfully developed into evaluation maneuvers. As a result, Phase I was completed with a list of 25 potential maneuvers to be considered for flight simulation and 58 additional maneuvers that had not been developed as fully. Some of the maneuvers not tested in simulation may be valuable for future development; therefore, the maneuvers shown in Figure 34 and other maneuver candidates are contained in Appendix A. Some of the maneuvers in Appendix A may be redundant with other STEMS maneuvers or may not prove useful; however, they are provided as a source of ideas for future maneuver development. Additionally, maneuver evaluation forms and simulation comment cards were developed during Phase I. They were later refined during the Phase II simulations, and the final versions of these forms are included in Chapter 2.

	Maneuvers Refined	
	Maneuver	**Notes**
295	Straight and Level Acceleration	Promising maneuver, not yet developed and tested in simulation
302	Straight and Level Deceleration	Promising maneuver, not yet developed and tested
303	Turning Deceleration	Promising maneuver, not yet developed and tested
313	Pitch Attitude Capture	Developed into STEM 7 - Nose-Up Pitch Angle Capture
312	Maximum Pitch Pull	Developed into STEM 6 - Maximum Pitch Pull
316	Pitch Unload	Use existing maneuver, STEM 16 - 1-g Stabilized Pushover
237	Bank-to-Bank Roll	Promising maneuver, not yet developed and tested
307	Loaded Roll and Capture	Developed into STEM 13 - High AOA Roll and Capture
310	Lateral Gross Acquisition	Use existing maneuver, STEM 3 - High AOA Lateral Gross Acq.
286	Maximum Sideslip	Promising maneuver, not yet developed and tested
79	Arrest High Sink Rate	Promising maneuver, not yet developed and tested
299	Offset Approach to Landing	Promising maneuver, not yet developed and tested
305	Turn Entry	Dropped after sim and TFS test - Insensitive to Design Parameters
290	Maximum Rate Level Turn	Developed into STEM 15 - Minimum Time 180° Heading Change
14	Acceleration to Loop	Developed into STEM 14 - Minimum Speed Full Stick Loop
99	Hammer Head	Promising maneuver, not yet developed and tested
184	Terrain Following/Terrain Avoidance	WL pursuing development of Slalom/Dolphin
	Maneuvers Eliminated	
	Maneuver	**Notes**
9	Freestyle High-Speed Acceleration	Better data from separate pitch unload and acceleration tasks
192	Maximum Pitch Pull from Level Turn	Eliminate in favor of 312
250	Pitch Agility Task	Too many maneuver elements to analyze, not operational
308	Maximum Rate Roll	Learn nothing new over 307
150	Loaded Roll	Learn nothing new over 307
249	Roll Agility Task	Similar attributes as 307 and 310 (307 and 310 more repeatable)
43	Instrument Approach, Final Segment	Not demanding enough
306	Heading Capture	Not operational, learn nothing new over other maneuvers
58	Rolling Pull-Up	Similar attributes as 305, pursue 305 instead
267	Defensive Gun Attack	Complicated, expect chaotic results
113	Freestyle High-Speed Reversal	Complicated, expect chaotic results
141	Transition from Pop to Target Attack	Learn nothing ne
98	Two-Circle Lufbery Vertical Reverse	Learn nothing new over 307, 310
247	Unloaded Turn Reversal	Learn nothing new over 307, 310
200	Unnamed	No new attributes evaluated
	New Maneuvers Identified	
	Maneuver	**Notes**
319	Go-Around Maneuver	Evaluate transients to clean-up aircraft and accelerate
320	Optimum Acceleration	Freestyle maneuver
323	Unload from Climax	Evaluate nose-down control from loaded condition
324	Sideslip Tracking	Directional flying qualities task
325	Axial Tracking	Axial precision flying qualities task
326	Axial Acquisition	Axial decel and accel acquisition flying qualities task

Note: Numbers shown in the left-hand column are temporary STEM numbers and should not be confused with the final STEM numbers shown in the notes column and in Reference 3. The numbers in the left-hand column can be used to locate maneuver descriptions in Appendix A.

Figure 34. Results of the Review Team Meeting Prior to Simulation Effort

Maneuver Development and Refinement Using Piloted Simulation

Phase II of this contract was used to develop, test, and refine evaluation maneuvers through piloted simulations. Three simulations were conducted and each simulation was structured to have a slightly different approach and objectives. The first simulation was designed to be exploratory. Several maneuvers were defined, preliminary data was taken, and the analysis tools and techniques were tested and evaluated. A period of data analysis was conducted after the simulation to evaluate the maneuvers. If the maneuvers successfully passed the Review Team analysis, then the maneuver was finalized. Otherwise, it was either refined in the next simulation or removed from future consideration. Also adjustments in the test procedures and analysis techniques were made prior to the second simulation. The second simulation was used to develop a few new maneuvers, but it mainly served as the primary data gathering effort. Again, the maneuvers were reviewed to determine which required additional testing in the third simulation. The final simulation was then used to complete a final refinement of maneuvers, develop a few new maneuvers, validate some of the maneuvers with a different simulation model, and evaluate the flight test plan.

The first simulation was designed to be exploratory so that a maximum number of maneuvers could be investigated and the simulation test approach could be evaluated. The simulation was conducted during a five-day period and included approximately 30 hours of simulation test time. Approximately 15 maneuvers were developed and additional variations, such as testing different flight conditions and capturing various pitch attitudes, were flown for several of the maneuvers using the GENAIR fighter model described in Chapter 3. Design parameter variations were tested for each maneuver to begin investigating the sensitivity of the maneuver to primary design parameters. A limited amount of data was collected during the first simulation so that more maneuvers could be screened and developed. Typically, data was gathered from a single pilot for each maneuver. (Data was taken from two pilots on a few maneuvers.) A total of six pilots participated during the week of simulation and their schedules were such that there were always four pilots participating at any one time. There were always two operational pilots and two test pilots available to fly the maneuver and help in the maneuver development. This was intended to ensure that the maneuvers would have strong links to operational and test requirements. Additionally, there were four engineers that participated for at least some portion of the week.

Several observations were made from the first simulation that resulted in a more efficient second simulation. First, post-simulation data processing indicated that data was required from

at least two pilots before any strong conclusions could be made about that maneuver. Data from a minimum of two pilots is needed to measure the pilot variability that is to be expected from the maneuver. However, data from a single pilot was generally sufficient to determine if the proper design parameters and ranges were being tested. Second, it was determined that only one operational pilot and one test pilot were needed at any one time to support the maneuver development and data gathering process. This was evident because the two test pilots tended to agree and the two operational pilots tended to share the same perspective. However, it was valuable to have at least one pilot experienced in each specialty because of the unique insights. Another conclusion from the first simulation was that more time should be spent flying the maneuvers and less time should be spent discussing them. Seemingly infinite discussions could be resolved much quicker by trying various techniques for a maneuver in simulation. Additionally, some of the simulation tools and evaluation forms were updated as a result of observations during the simulation.

The second simulation was designed to gather the bulk of the data for this contract as well as begin validating the maneuvers with a more complex simulation model. This simulation was conducted over a two-week span that included 7 days of testing and approximately 49 hours of simulation test time. A total of 14 maneuvers was flown. Four new maneuvers, that were not developed in the first simulation, were developed and tested during the second simulation. The majority of the simulation time was devoted to testing design parameter variations because most of the maneuvers had been developed previously. Data was gathered from one additional pilot to augment the first simulation data for some maneuvers. At least two pilots' data was taken in cases where the test matrix needed revising between the first and second simulations. In a few cases, data was gathered from four pilots so that pilot variability could be investigated in more detail. Some of the simulation time was used to begin validating the maneuvers in a high fidelity F/A-18C aircraft model. The maneuvers were developed and design parameter variations were tested using the GENAIR fighter model. As a result, the more complex F/A-18C model was used to check the flyability of some of the maneuvers. A total of four pilots participated in the second simulation (two pilots were available during the first week of testing and two different pilots were available during the second week). One test pilot and one operational pilot were available for maneuver development and data gathering at any one time.

The second simulation was much more efficient than the first because of the progress made and lessons learned during the first simulation. Many of the maneuvers had already been developed during the first simulation, so some of them were simply flown for additional data while others were slightly modified based on the Review Team inputs. Also, the test matrices

had been previously evaluated and either verified or refined prior to the second simulation, so the data gathering tended to operate more smoothly. In general, the simulation time was used more effectively because more time was flying maneuvers and trying variations and less time was spent discussing them. The people participating were also used more effectively because only two pilots and two engineers were on hand at any one time. Finally, the second simulation spanned two weeks, so it allowed simple modifications to the test matrices or simulation setup between weeks.

The third simulation was used to gather final data, test if this evaluation maneuver process could be applied to transport class aircraft, validate the maneuvers with a high fidelity simulation model, and evaluate the flight test plan. The majority of the simulation was conducted in a 5 day period that included approximately 40 hours of simulation test time. Additional days, and approximately 14 hours of simulation test time, were used for more validation and to evaluate the flight test plan. Fourteen maneuvers were flown during this simulation, including 4 new maneuvers. The data gathering procedures for the third simulation were slightly modified from the second simulation. During the second simulation, all the maneuvers were flown for numerical measure of merit data, and subsequent data analysis concentrated of quantitative data. However, during the third simulation, some maneuvers were flown only to collect pilot comments because previous data analyses had indicated the inability to use quantitative data from certain maneuvers. In particular, some of the flying qualities maneuvers were flown solely for comments and not for measure of merit data because similar maneuvers resulted in very poor quantitative data. Also, some of the previously developed maneuvers were tested to determine if they could be flown with alternate command types, such as an angle of attack rate command system. These maneuvers were flown briefly to check for flyability and gross trends with design parameter variations.

The flight test plan portion of the third simulation was designed to gather much different information than the design parameter testing. A simplified NASA High Alpha Research Vehicle (HARV) model was used so that the performance characteristics would be representative of flight test. (The HARV is currently the most likely aircraft to be used to validate STEMS in flight test.) This test was conducted to identify any changes in setup that might be required for the HARV and to get a preliminary idea of the flight time required to validate STEMS. Additional simulation work with a higher fidelity HARV model is recommended prior to flight test. Reference 5 contains the flight test plan and additional details of this testing.

Validation of most of the maneuvers using a high-fidelity simulation model (MuSIC) was also conducted during the third simulation. A relatively simple model (GENAIR fighter model) was used to develop the maneuvers, so a complex simulation model with different performance and flying qualities was used to help validate the maneuvers. The maneuvers were flown to determine if the setups were tolerant to wide aircraft performance changes and if the maneuvers were flyable with a high fidelity simulation model. All of the maneuvers that were tested with the MuSIC model proved to be flyable and applicable. The MuSIC model was also used to evaluate limited design variations with some of the maneuvers.

The GENAIR transport model was flown during the third simulation to test the ability to use this maneuver development process for other classes of aircraft. Only four maneuvers were tested, but the results indicated that this process could be extended to other classes of aircraft. The "Tanker Boom Tracking" maneuver (STEM 18) was found to be a useful evaluation maneuver; the "Tracking in Power Approach" maneuver (STEM 19) and the "Nose-Up Pitch Angle Capture" maneuver (STEM 7) appeared to be possibly valuable but could use additional validation; and a flight path capture maneuver was tried but was not found to be useful. Design parameter variations were also tested with the transport aircraft, and the data obtained indicates that the STEMS process can be used in the design of a transport class aircraft also.

Data Analysis and Evaluation of Maneuvers

Periods of data analysis were performed between each simulation to evaluate and refine the maneuvers. This analysis was used to determine the following characteristics: repeatability and testability of the maneuver, ability of maneuver to provide useful design information, value of comments and measure of merit generated, relation of the maneuver to operational applications, and the potential for GLOC or spatial disorientation. This analysis and review was used to modify maneuvers that were deficient in some way. A maneuver was accepted as a STEM if it successfully met most of these criteria. A maneuver was dropped if it failed many of these checks. A combination of quantitative and qualitative analyses were conducted on the simulation data to evaluate each maneuver. Several pieces of data were generated from the design parameter variation testing, including the following: numerical measures of merit , pilot comments, pilot ratings, maneuver summary comment cards, and human factors analyses. All of this data was reviewed, as shown in Figure 35, to evaluate the relative success or failure of the maneuvers. The data was also analyzed for its applicability to the design process. Each maneuver was then either accepted, eliminated, or modified based on Review Team analysis of the simulation data.

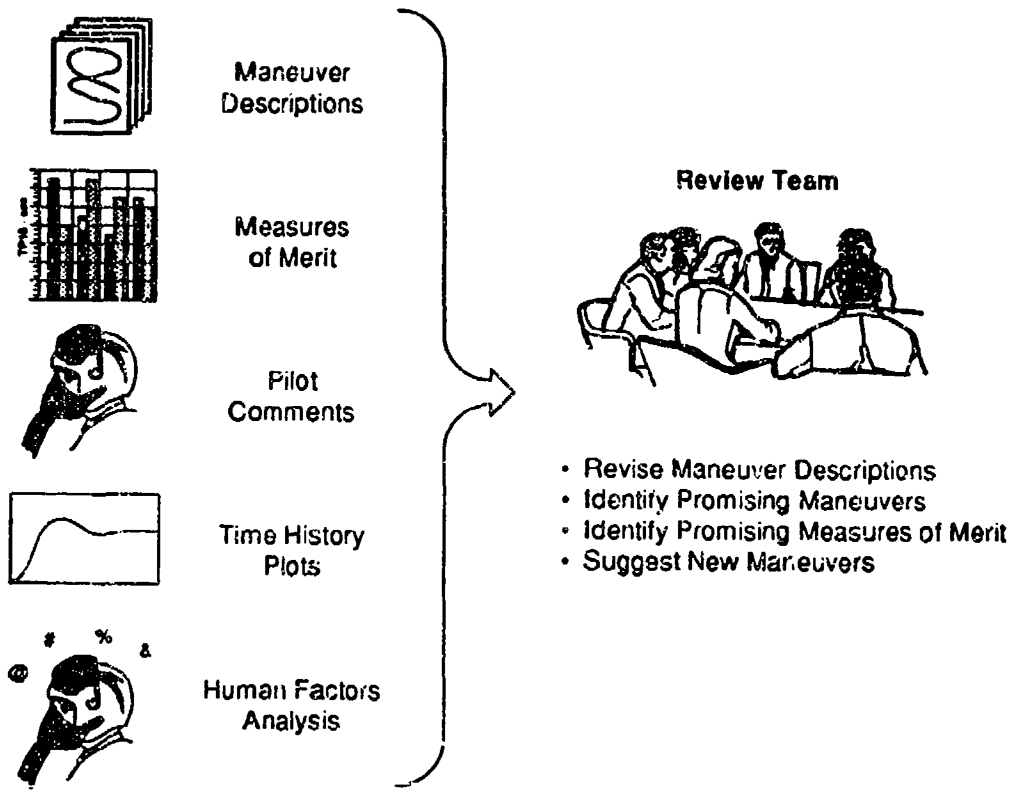


Figure 35. Review Team Sources of Data to Evaluate Each Maneuver

Summary results will be shown in Chapter 5 for each maneuver that was accepted as a STEM. An example will be used in this chapter to describe the steps conducted during the data analysis and maneuver evaluation. A much more complete set of data for each maneuver is included in Reference 4. The summary results shown in this report simply demonstrate sample findings and sensitivities. In general, the results for each maneuver are dependent upon the design parameters chosen and the range of variation tested. For example, a valuable evaluation maneuver might be sensitive to changes in short period frequency but not very sensitive to time delays. This maneuver could be judged incorrectly if it were evaluated by only testing time delay variations. The range of design parameter variation conducted also strongly influenced the measure of merit analysis. Therefore, the results shown in these reports are not meant to be an exclusive list of design parameters for each maneuver.

Quantitative Data Analysis

The quantitative data analysis was conducted by calculating time history measures of merit and evaluating the ability to use this information to modify a design. The goal of this procedure was to evaluate the sensitivity of the measure of merit to design parameter variations

and to pilot variability. This was done to isolate measures of merit that were sensitive to design parameters but exhibited little pilot variability. Measures of merit with these characteristics could be "trusted" for design guidance. In summary, this process compared the change in a measure of merit due to a design parameter variation to the variation that was due to differences in pilots. The result is a cross matrix that identifies how well each measure of merit can be used to evaluate the changes in each design parameter for a given maneuver. It was found that some measures of merit might effectively measure one design parameter variation but not another. Therefore, it is dangerous to rely on a single measure of merit when making a variety of design parameter changes.

A screening process was conducted for each maneuver to select the most appropriate measures of merit. First, the Review Team generated a list of assorted potential measures of merit. A large number of measures of merit were calculated from the time history data using an automated process. The measures of merit were intentionally selected to be simple to calculate, and therefore, easier to measure in a flight test environment. They were also selected to be meaningful from both design and operational standpoints. Measures of merit that obviously were not applicable to a certain maneuver were not calculated for that maneuver, but any that seemed even remotely possible were investigated. Figure 36 shows a list of the measures of merit that were considered during this study. This list is meant to be representative of typical measures of merit and is not intended to an all-encompassing set. All of the measures of merit were calculated from simple time history signals that are readily available from a simulation model, and most should be available from flight test. The measures of merit are described in more detail in Reference 4.

Statistical tests were conducted after calculating the measures of merit to determine which measures were sensitive to design parameter variations. The statistical calculations were used to isolate the effects of each design parameter variation and the amount of pilot variability present in each measure of merit. The results of the statistical analyses were summarized in both numerical and graphical forms for the subsequent Review Team analysis. Several analyses were conducted for certain maneuvers. For example, several different pitch attitudes were used to test a pitch angle capture maneuver. A separate statistical analysis was conducted for each angle capture. Also, multiple analyses were conducted to compare the results from fractional factorial testing to full factorial testing when enough data was available. A complete set of data, including the numerical and graphical summaries, is included in Reference 4, and some sample summary information is shown in Chapter 5.

Abbreviation	Description
TPXDEG	Time to pitch through an X' pitch attitude change
CLMAX	Maximum lift coefficient attained during the maneuver
TCLMAX	Time at which CLMAX was attained
QD0AVG	Average pitch acceleration over the first X seconds
QDXSEC	Pitch acceleration X seconds after initiation of the maneuver
QDMAX	Maximum pitch acceleration
TQDMAX	Time at which maximum pitch acceleration occurs
QMAX	Maximum pitch rate
TQMAX	Time at which maximum pitch rate occurs
QXSEC	Pitch rate at X seconds
AOADMX	Maximum AOA rate
TADMAX	Time at which maximum AOA rate occurs
ADXSEC	Angle of attack rate at X seconds
NZMAX	Maximum load factor
TNXMAX	Time at which maximum load factor occurs
NZDMAX	Maximum load factor rate
TNZDMX	Time at which maximum load factor rate occurs
THTMAX	Maximum incremental pitch attitude
TTHTMX	Time at which maximum pitch attitude occurs
AOAMX	Maximum angle of attack attained during maneuver
TAOAMX	Time at which maximum AOA occurs
AOAXSEC	Angle of attack at X seconds
DELAOA	Change in angle of attack from initial time to final time
TAOA50	Time to reach 50' angle of attack
TCAPTR	Time from initial time until capture occurs
TCMPLT	Time to complete the maneuver
TSETTL	Settle time (time to capture after the target first enters the error band)
DELH	Increment in altitude between initial time and final time
DELHDG	Increment in heading between initial time and final time
TDHDG	Time to achieve the increment in heading change
DELPHI	Wind axis bank angle at the capture
PMAXACT	Maximum stability axis roll rate attained
TPMAX	Time at which maximum stability axis roll rate occurs
PDMAX	Maximum stability axis roll acceleration attained
TPDMAX	Time at which maximum stability axis roll acceleration occurs
PDMAXN	Maximum roll deceleration occurring from a lateral stick cross-check
PHIOVR	Bank overshoot (integral of stability axis roll rate from cross-check until zero rate)
PS	Specific excess power at the final time
ENERGY	Increment in specific energy between the initial time and the final time
VDOTMX	Maximum rate of change of equivalent airspeed
DELV	Increment in equivalent airspeed between the initial time and the final time
GAMDOT	Maximum flight path rate
TGAMD	Time at which the maximum flight path rate occurs
LONRMS	Root Mean Square of longitudinal stick position
LATRMS	Root Mean Square of lateral stick position
ELERMS	Root Mean Square of elevation tracking error
AZIRMS	Root Mean Square of azimuth tracking error
LONDEV	Longitudinal position deviation upon touchdown for the landing task
LATDEV	Lateral position deviation upon touchdown for the landing task
TDV	Touchdown speed deviation for the landing task
CHR	Cooper-Harper Rating
PRR	Pitch Recovery Rating
PXSEC	Roll rate at X seconds
PDXSEC	Roll acceleration at X seconds
GAMRMS	Root Mean Square of flight path error

Figure 36. Measures of Merit Calculated During the Generic Fighter Testing

An example maneuver and its corresponding data analysis will be used to help describe and document the maneuver evaluation process used for this contract. A low-speed, maximum pitch maneuver will be used as an example. This is a very simple, open-loop maneuver designed to test the maximum pitch capabilities of an aircraft. The pilot first stabilizes at the desired AOA and airspeed; then he performs an aggressive full-aft stick input and continues to hold aft stick. The maneuver is terminated when the aircraft reaches its maximum pitch attitude. Variations in short period frequency (WSP), short period damping (ZSP), and maximum attainable angle of attack (AOAMAX) were tested for this example.

A graphical summary of data from the maximum pitch pull analysis is shown in Figure 37. The bars indicate the average value for each measure of merit for each level of the design parameter tested. The first six bars on each graph indicate the average measure of merit value for each variation in design parameter. The difference between the light and dark bars indicates the change in measure of merit that is due to the change in that design parameter. The last two bars on each graph indicate the overall average measure of merit value for each of the two pilots. The change between these last two bars indicates the difference that can be attributed to pilot technique. A statistical significance level is also associated with each of these sets of bars to indicate the credibility of the statistical calculations (amount of noise or unaccounted for factors). The significance level is not shown in Figure 37, but it was taken into consideration during the evaluation process.[4]

The sensitivity of each measure of merit to each design parameter and to pilot variability was analyzed and grouped into categories to indicate the relative strength of that sensitivity. The percent change in a measure of merit due to a design parameter change was combined with its statistical significance to indicate if there existed a strong, potentially strong, potentially weak, or a weak degree of sensitivity. If the dark and light bars in Figure 37 vary considerably and the statistical tests indicated a high degree of confidence in the averages, then it is considered a strong sensitivity. As the relative change decreased in magnitude or the statistical significance declined, then the sensitivity was classified at a lower level. A summary of this analysis, for the maximum pitch pull maneuver, is shown on the left hand side of Figure 38. The pilot variability for a measure of merit was judged by comparing the difference in averages due to a design parameter variation to the difference in averages between the pilots. If the change due to the design parameter was much larger than the change due to pilots, that combination of design parameter and measure of merit was considered to have minimal pilot variability. Increasing amounts of pilot variability were labeled as "some variability" or "large variability." A

summary of the pilot variability for the maximum pitch pull maneuver is shown on the right-hand side of Figure 38.

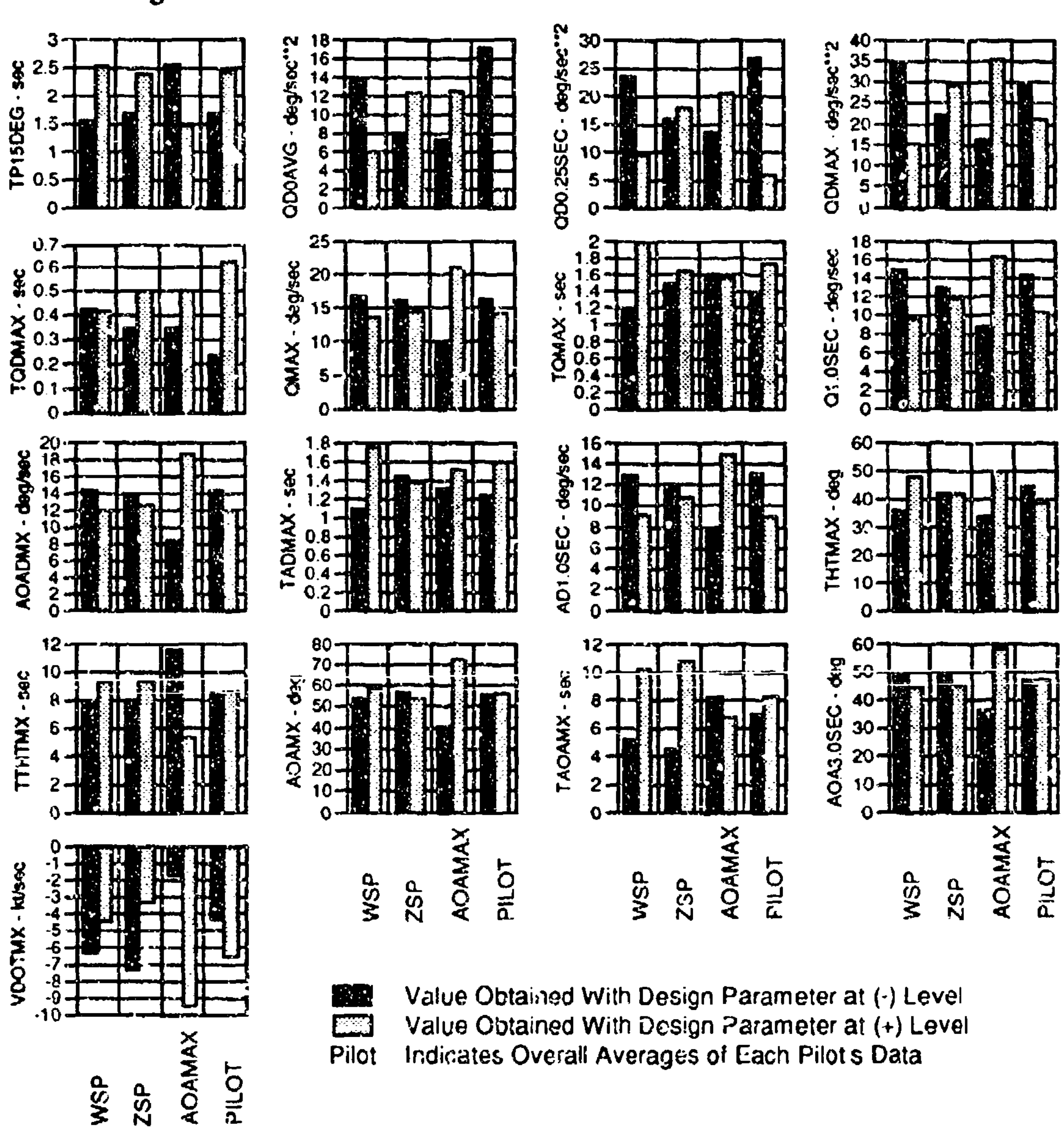


Figure 37. Example Measure of Merit Data for Maximum Pitch Pull Maneuver

The sensitivity to design parameters was then combined with the sensitivity to pilot variability to form an overall indication of the ability to use a particular measure of merit when making modifications to a design parameter. Figure 39 shows a summary of these overall sensitivities for the example pitch pull maneuver. The dark regions indicate combinations of design parameters and measures of merit that can be trusted during the evaluation of an aircraft. The dark gray combinations represent a slightly reduced confidence for design applications and the light gray or white regions are probably unacceptable for designers. A detailed description

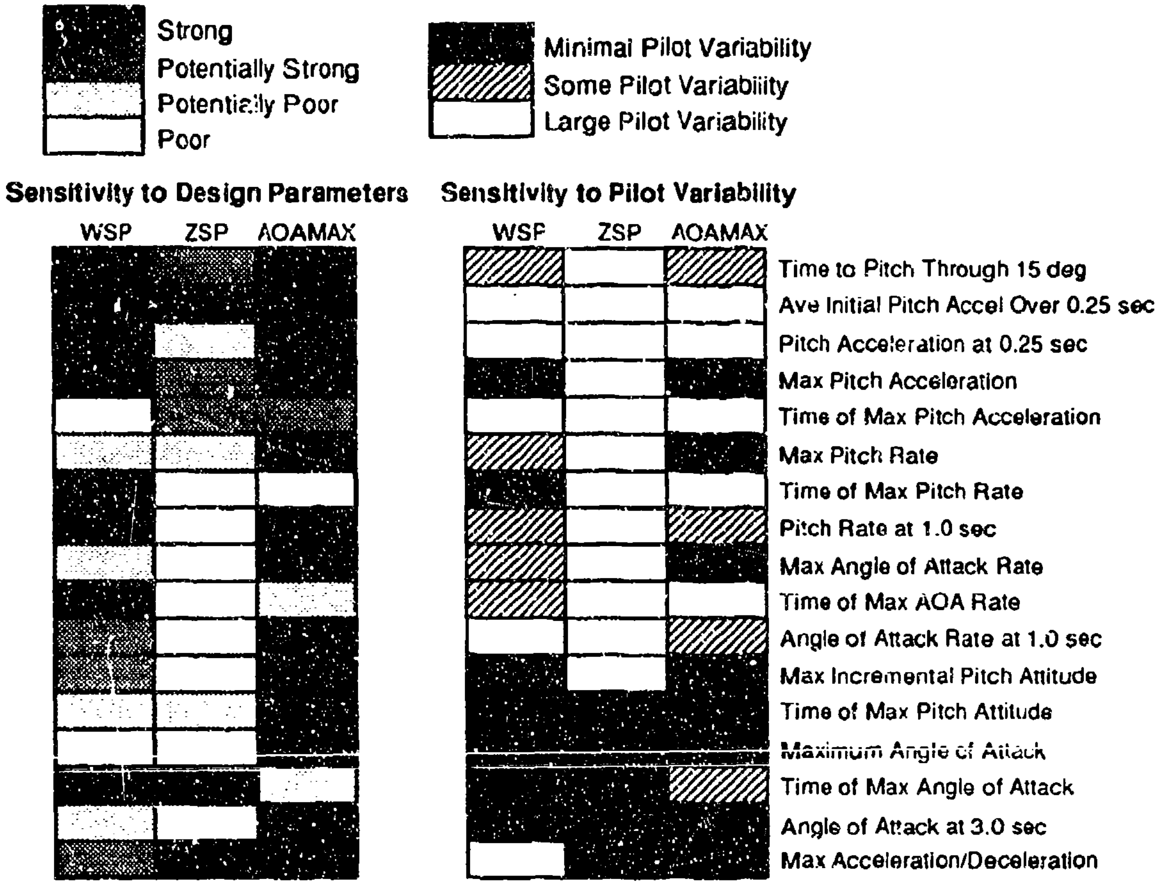


Figure 38. Design Parameter Variations and Pilot Variability

of the rules used to classify the sensitivities and pilot variability is included in Reference 4. Typical overall sensitivities will be shown for several maneuvers in Chapter 5. Measures of merit or design parameters that fell into the lower two categories will be removed from the figures in Chapter 5 for simplicity. A complete set of sensitivity figures is included in Reference 4.

It became obvious after the second simulation that some of the maneuvers did not tend to generate good measures of merit. In general, maneuvers that were highly closed-loop, such as tracking tasks, failed to produce many successful measures of merit. Therefore, the measure of merit analysis was not performed on similar maneuvers that were flown during the third simulation. This analysis also was not conducted on tests that were used to validate the maneuvers with the MuSIC simulation model or tests used to validate the maneuvers for alternate pitch command systems.

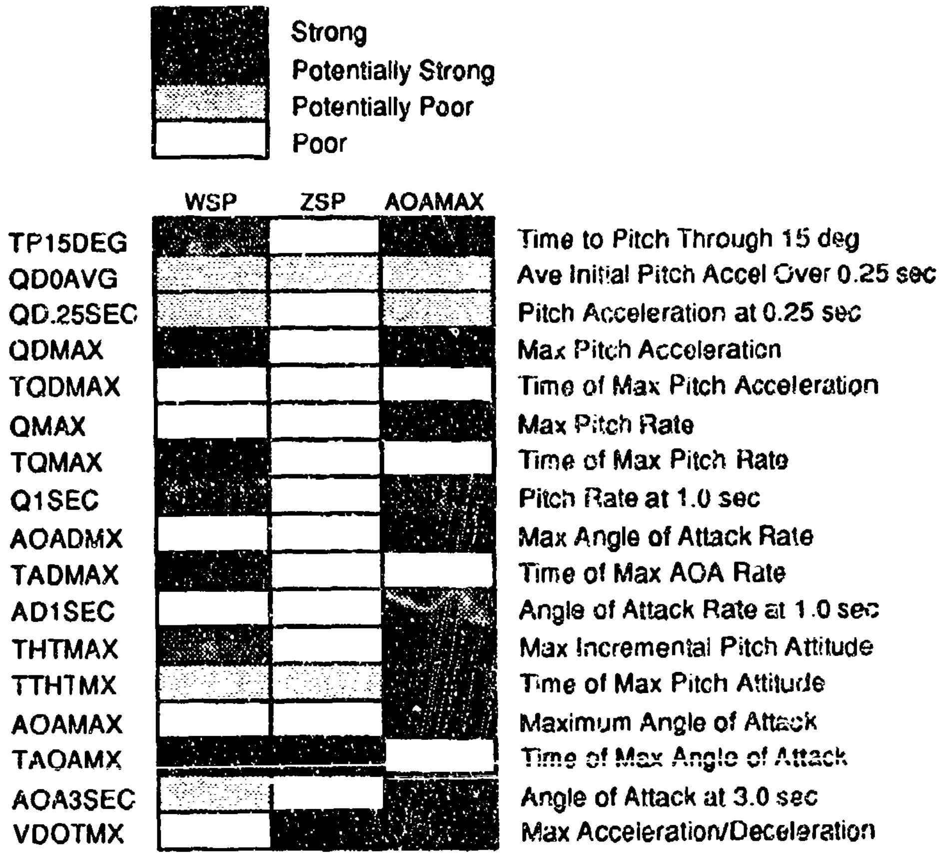


Figure 39. Example Overall Sensitivities of Measures of Merit for Max Pitch Pull

Qualitative Data Analysis

Qualitative data was also studied for each potential evaluation maneuver. This data included the following: pilot comments, pilot ratings, and simulation comment cards. The Review Team was primarily looking for key comments and data that can be used to direct design modifications. They compared pilot opinions to see if consistent characteristics were observed and if constructive comments that isolated aircraft attributes were obtained. Pilot ratings were also examined to determine if the ratings were consistent with the comments received and if the ratings seemed reasonable for the dynamics being tested. This step required the experience of flying qualities engineers to evaluate the quality and content of the comments relative to the design parameter changes tested. Additional valuable information was obtained from the summary comments given by the pilots during the simulation. The pilots described attributes of a maneuver and their perception of it immediately after evaluating all of the design parameter variations by using the comment card shown in Chapter 2, Figure 15. All of this information was used to understand the maneuver better and suggest possible refinements if necessary.

The qualitative data is very difficult to summarize, so the complete pilot comments, ratings, and responses to the simulation comment card are included in Reference 4, and only summary conclusions about the ability or inability of a maneuver to generate useful qualitative data will be included in Chapter 5.

Human Factors Analysis

All of the simulations were conducted in a fixed-base dome, so additional analyses were performed to identify potential motion effects. The linear and angular accelerations experienced by a pilot in flight depend upon the aircraft dynamics, location of the pilot station, cockpit configuration, and other aircraft dependent characteristics. Additional factors such as inner ear and brain stem anatomy, diet, sleep patterns, vision, and weather also play a role in motion effects on a pilot. However, analyses were conducted to try to identify maneuvers that would be potentially dangerous in flight. More specifically, GLOC and spatial disorientation were considered. A qualitative assessment of the maneuvers was performed before the first simulation to try to isolate potential motion considerations. Time history data was recorded and pilot questionnaires were completed during the simulations to determine if any problems could be anticipated during flight. Load factor time history data for all of the maneuvers was evaluated using the Dynamic Acceleration Compute Model (DACM). The DACM predicted no possibility of GLOC in the maneuvers. This is primarily due to the low speed nature of the maneuvers and the subsequently minimal load factors experienced. Unfortunately, due to the extremely complex nature of spatial disorientation, it is difficult to predict. Some computer models are currently being developed but were not used in this research. Instead, a qualitative evaluation was performed based on answers to the human factors pilot questionnaire shown in Chapter 2, Figure 16. The rating scales used to summarize susceptibility to GLOC and spatial disorientation are shown in Figure 40. Figure 41 contains the results of the human factors analysis of the STEMS maneuvers and indicates no strong potential cases of GLOC or spatial disorientation.

Evaluation of Maneuvers

A Review Team analysis of the simulation data was conducted after the first and second simulations. The Review Team was furnished with the following information: maneuver descriptions, statistical summaries of the measure of merit analysis, time history plots, pilot comments and ratings, responses from the simulation comment cards, and results of the human factors analysis. They were asked to review the pieces of data that were most meaningful to

them. Each Review Team member analyzed the data from a slightly different perspective and responded with different types of inputs. The primary goal of the Review Team analysis was to evaluate the quality of the data generated from each maneuver, determine the applicability of each maneuver to the design process, and judge its relevance to operational use.

Gz-Tolerance *			Gx,y - Tolerance *		
Rating	Injury	Description	Rating	Injury	Description
0	None	No Pred. Difficulties	0	None	No Pred. Difficulties
1	Possible	Possible gray/blackout >4-6 instantaneous	1	Possible	Possible Injury (0-1G)
2	Probable	Probable gray/blackout 6-8 instantaneous	2	Probable	Probable injury (1-2G)
3	Definite	Definite blackout 7+ instantaneous	3	Definite	Incapacitating injury (2+G's)

* Aircrew wearing standard G suit/straining

Spatial Disorientation **		
Rating	Category	Description
0	None	No predicted difficulties
1	Possible	Possibility of SD (2 planes or movement/rapid)
2	Probable	High Probability of SD (2-3 planes/rapid)
3	Definitely	SD Inevitable (3 planes/rapid movement)

** Assumption: clear VFR day

Figure 40. G-Tolerance and Spatial Disorientation Rating Scales

Some key considerations were identified during the Review Team analysis. It was observed that differences in the data due to design parameter variations needed to be much greater that the amount of pilot variability in the data. This is an important consideration for all of the data, but was most easily applied to the quantitative measure of merit analyses. In other words, if measures of merit are to be calculated for a maneuver, it is essential that they be relatively insensitive to variations between pilots yet sensitive to variations in the design. It

was concluded that measures of merit, and other types of data, were useless to a designer if the data is more sensitive to the pilot than the configuration dynamics. Two major factors were used to substantiate this opinion. First, it cannot be assumed that the same pilot will be available during all of design and flight test, so data that is to be used in a comparative fashion needs to be relatively free of pilot variability. Second, the data should have a strong correlation back to design parameters. If a design parameter is adjusted, then the data must accurately reflect any performance changes rather than being overwhelmed by pilot variability. Pilot comments and ratings were also considered as key sources of evaluation data. Therefore, they were examined for useful design feedback information by comparing the comments to the parameter variations tested and looking for key comments that would be meaningful for design modifications. After reviewing the simulation data, each Review Team member completed the evaluation form shown in Chapter 2, Figure 13. This form was intended to provide useful information to improve a maneuver. The Review Team members were also asked to identify each maneuver as being sufficiently complete, needing refinement, or not worth retaining.

Maneuver Number	Name	Human Factors Estimate Gz	Gx,y	SD	DACM Results	SD Pilot Responses
1	Tracking - High AOA Sweep	0	0	0	No GLOC	-
4	Dual Attack	1	0	0	No GLOC	0 Yes, 2 No
5	Rolling Defense	1	0	1	No GLOC	2 Yes, 0 No
6	Maximum Pitch Pull	1	0	0	No GLOC	0 Yes, 2 No
7	Nose-Up Pitch Angle Capture	1	0	1	No GLOC	1 Yes, 2 No
9	Pitch Rate Reserve	1	0	0	No GLOC	-
11	Sharkenhausen	1	0	0	No GLOC	0 Yes, 3 No
12	High AOA Roll Reversal	1	0	0	No GLOC	1 Yes, 1 No
16	1-g Stabilized Pushover	0	0	0	No GLOC	0 Yes, 2 No
17	J-Turn	1	0	0	No GLOC	-
20	Offset Approach to Landing	1	0	1	No GLOC	0 Yes, 2 No

Data not analyzed for the following STEMS:

2 High AOA Tracking - Maneuver tested under other research.
3 High AOA Lateral Gross Acquisition - Maneuver tested under other research.
8 Crossing Target Acquisition and Tracking - Benign motion, not analyzed.
10 High AOA Longitudinal Gross Acquisition - Maneuver tested under other research.
13 High AOA Roll and Capture - Same motion environment as 12, not analyzed
14 Minimum Speed Full Stick Loop - Not analyzed due to time constraints.
15 Minimum Time 180° Heading Change - Not analyzed due to time constraints.
18 Tanker Boom Tracking - Benign motion, not analyzed.
19 Tracking in Power Approach - Benign motion, not analyzed.

Figure 41. Summary of Human Factors Predictions and Analysis

Flight Test Validation

The maneuvers defined under this contract were developed in fixed-base simulation; therefore, it is necessary to validate them with in-flight testing. This validation has been started by the US Air Force Test Pilot School as two class projects. Six STEMS maneuver candidates ("High AOA Tracking" - STEM 2, "High AOA Lateral Gross Acquisition" - STEM 3, "Rolling Defense" - STEM 5, "High AOA Longitudinal Gross Acquisition" - STEM 10, "1-g Stabilized Pushover" - STEM 16, and "Maximum Performance Turn Entry") were flown and evaluated for the ability to use them in a flight test environment.[14,15] The six maneuvers were flown with generally good success except for the "Maximum Performance Turn Entry" (which has since been eliminated from consideration for STEMS). Some of the maneuvers had to be flown at lower AOA than the maneuvers were really intended for because of aircraft limitations. Therefore, it would be very beneficial to validate the STEMS maneuvers on an aircraft with high AOA capability. Currently, the NASA F-18 HARV would probably be the best aircraft to use for a STEMS validation flight test program because of its high AOA abilities. Other aircraft such as the F-16 MATV (Multi-Axis Thrust Vectoring), X-31, or potentially the NASA F-15 S/MTD ACTIVE (Advanced Controls Technologies for Integrated Vehicles) research aircraft are also capable of completing a satisfactory STEMS validation flight test program.

Some of the maneuvers ("High AOA Tracking" - STEM 2, "High AOA Lateral Gross Acquisition" - STEM 3, "High AOA Longitudinal Gross Acquisition" - STEM 10, and "1-g Stabilized Pushover" - STEM 16) have been or will soon be flown on the F-18 HARV. STEM 16 has also been flown on a production F-18. These maneuvers have proved useful for in-flight testing. However, it would still be valuable to include these maneuvers into a STEMS validation flight test program so that they can be directly compared to all of the STEMS maneuvers.

A preliminary flight test plan was developed and tested under this contract to help transition the maneuvers to a flight test program. It can be found in Reference 5. The plan is not meant to be a final version. Instead, it is intended to be an intermediate step between the maneuver development conducted in fixed-base simulations and the validation of the maneuvers in flight test. The plan is written somewhat generically so that it can be used as a starting point for any aircraft evaluation that uses the STEMS maneuvers. However, it does include some specific HARV data to help initiate a validation test program on the HARV. However, it is recommended that additional simulation with a higher fidelity simulation model be conducted prior to flight.

A few hours of simulation was conducted to evaluate and refine the flight test plan. A simplified HARV model was used to determine if any maneuver setups had to be altered because of the performance differences between the HARV and the generic configuration used to develop the maneuvers. The simulation was also conducted to help determined approximate maneuver duration, setup times, and energy lost during the maneuver. Maneuver setups were also altered, if necessary to allow the HARV to remain in the Research Flight Control System (RFCS) envelope, thus allowing the use of pitch and yaw vectoring.[31] Simulation data and previous flight test experience were used to help estimate the flight time required to validate the STEMS.

Chapter 5
Summary of Design Parameter Variation Data

As described in Chapters 2 and 4, several pieces of simulation data were reviewed to analyze the potential applicability of each maneuver to the design process. This data included time history measures of merit, pilot comments and ratings, responses to simulation comment cards, and other information. Summaries of some of the typical measure of merit results for each maneuver are presented in this chapter. A complete listing of the data gathered during the maneuver testing is included in Reference 4 As described earlier, these measures of merit were analyzed using statistical analyses of the simulation configurations, and the procedure outlined in Chapter 4 was used to evaluate the measures of merit. The results obtained were dependent upon the design parameters selected and the ranges of variation tested. Therefore, this is not meant to be a recommendation for any specific set of measures of merit or design parameters.

A brief overview of the maneuvers and design parameters tested under this research is shown in Figure 42. The design parameters tested during this research were detailed in Chapter 3, Figure 22. Figure 8, Chapter 1, should be consulted for additional maneuver characteristics such as the axis being evaluated, appropriate flight envelope, etc. Each maneuver that was accepted as a STEM will be briefly described in this chapter and some typical measure of merit results will be shown. Reference 3 contains the complete maneuver description and Reference 4 contains a full set of data including the pilot comments. Only the measures of merit that resulted in reasonably good success will be shown in this section. Also, measures of merit were not calculated for all of the maneuvers because it was observed after the second simulation that certain types of maneuvers were not structured properly for repeatable numerical measurands. For instance, measures of merit were not calculated for all of the freestyle or tracking maneuvers because of the limited success observed from the first two simulations.

Maneuver Number and Name	Data: Quantitative	Data: Qualitative	Short Period Freq. (Includes CAP)	Short Period Damping	Maximum AOA	Longitudinal Stick Sensitivity	Longitudinal Stick Shaping	Lon. Command Type	CG Location	Longitudinal Dynamics†	Maximum Roll Rate	Roll Time Constant	Roll Acceleration Limiter	Lateral Dynamics†	Engine Time Constant	Time Delay	Thrust Vectoring Engaged/Disengaged	Vectoring Rate Limits
1. Tracking During High AOA Sweep		√	√	√							√	√						
2. High AOA Tracking		√	√	√							√	√						
3. High AOA Lateral Gross Acquisition	√	√									√	√						√
4. Dual Attack		√			√					√				√				√
5. Rolling Defense	√								√		√							
6. Maximum Pitch Pull	√		√	√	√													
7. Nose-Up Pitch Angle Capture	√	√	√	√		√	√									N		
8. Crossing Target Acq. and Tracking		√	√								√	√						
9. Pitch Rate Reserve	√		√	√	√	N												
10. High AOA Longitudinal Gross Acq.	√	√	√	√														√
11. Sharkenhausen	√	√			√					√				√				
12. High AOA Roll Reversal	√										√	√	√					
13. High AOA Roll and Capture	√	√									√	√						
14. Minimum Speed Full Stick Loop		√															√	
15. Minimum Time 180° Heading Change		√															√	
16. 1-g Stabilized Pushover	√								√									
17. J-Turn		√	√					√			√						√	
18. Tanker Boom Tracking		√	√	√								√						
19. Tracking In Power Approach		√	√	√							√	√						
20. Offset Approach to Landing		√	√	√							√	√			√	N		

√ Design Parameter Successfully Tested
N Design Parameter Not Successfully Tested
† Longitudinal Dynamics Indicates a Combination of Frequency and Damping Tested; Lateral Dynamics Indicates a Combination of Roll Mode Time Constant and Maximum Roll Rate

Figure 42. Design Parameters Evaluated With Initial STEMS Maneuvers

STEM 1: Tracking During High AOA Sweep

This maneuver is initiated with the evaluation pilot in trail of a cooperative target aircraft. The target enters a turn and the evaluation pilot evaluates his ability to track the target. The maneuver is designed such that the evaluation pilot must gradually increase AOA until tracking can no longer be conducted. This maneuver has a strong link to operational requirements and is a direct extension of the HQDT[1] technique to high AOA. It can be used to quickly evaluate longitudinal, lateral, and directional precision flying qualities over a wide AOA range and

identify potential problem areas. If any problems are uncovered, then the High AOA Tracking maneuver (STEM 2) can be used to isolate an AOA for closer investigation. Variations in short period frequency, short period damping, maximum roll rate (roll sensitivity), and roll mode time constant were tested to establish a sensitivity to design parameter modifications. Quantitative measures of merit were calculated but the results were so dominated by pilot variability that none were successful. The measures of merit are not shown here but are fully documented in Reference 4. Additional measures of merit could be investigated, but this maneuver appears to be best suited for qualitative data. The pilot comments and Cooper-Harper Ratings were of good quality and are shown in Reference 4.

STEM 2: High AOA Tracking

During this task, the evaluation pilot tracks a cooperative target aircraft in a turn. The maneuver is set up such that the evaluator can maintain a relatively constant AOA to thoroughly evaluate the tracking at that AOA. This maneuver is intended to expose air-to-air tracking flying qualities characteristics at high AOA for a single axis. A combination of precise tracking and small aim point corrections are used to evaluate tracking at a specific AOA. This maneuver was developed and tested under MDA Internal Research and Development[20,32,34] (IRAD) and NASA sponsored[18,33] high AOA flying qualities criteria development efforts. It is included as one of the initial STEMS maneuvers because of its applicability to high AOA and the fact that it is a relatively newly developed maneuver. This task has been used to develop longitudinal and lateral tracking criteria for variations in short period frequency, short period damping, maximum roll rate (roll sensitivity), and roll mode time constant at 30°, 45°, and 60° AOA. Design parameter variations were not conducted under the STEMS contract. References 18, 20, 33, and 34 should be consulted for specific pilot comments and ratings obtained with this task. In general, this task appears to be best suited for qualitative flying qualities data.

STEM 3: High AOA Lateral Gross Acquisition

This maneuver is set up such that the evaluation pilot can pull to a desired AOA, stabilize, and then roll to acquire a target aircraft. It was developed to help isolate the lateral axis for flying qualities evaluations at high AOA. Specifically, the controllability of the capture and the roll rate achieved can be evaluated. This maneuver was developed and extensively tested under MDA[20,32,34] and NASA sponsored[18,33] research. It is included as one of the initial STEMS maneuvers because of its applicability to high AOA and the fact that it is a relatively newly developed maneuver. This task has been used to develop lateral acquisition criteria for

variations in maximum roll rate (roll sensitivity) and roll mode time constant for 30°, 45°, and 60° AOA. Design parameter variations were not conducted under the STEMS contract. References 18, 20, and 33 should be consulted for specific pilot comments, ratings, and criteria obtained with this task. Reference 33 also includes measure of merit analyses conducted with this task. This task produces good flying qualities comments and data as well as providing some reasonably good quantitative information.

STEM 4: Dual Attack

This maneuver consists of the evaluation aircraft and two target aircraft. The targets fly straight and level with a 90° heading difference and the evaluation aircraft maneuvers between them to alternately acquire each target. The pilot can evaluate loaded roll capabilities as well as the ability to unload, roll, and pull to transition between the targets. This maneuver is an operationally relevant task that highlights the ability to reach high AOA and subsequently control the aircraft. The advantages of good high AOA roll performance can be demonstrated through this maneuver. Variations in longitudinal dynamics, lateral dynamics, and maximum AOA were evaluated with the generic fighter simulation model. The MuSIC model was also used to compare PST on and PST off modes. A typical summary of the measure of merit results from the generic fighter testing are shown in Figure 43. The variation in longitudinal dynamics (LONDYN) consisted of simultaneous variations in short period frequency and damping, and the variations in lateral dynamics (LATDYN) were tested by simultaneously varying maximum roll rate and roll mode time constant. Maximum angle of attack (AOAMAX) was varied between 40° and 60° to produce the results in Figure 43. Additional statistical tests were conducted to determine the significance of flying a loaded roll versus an unloaded roll technique (LOAD) and calculating the measures of merit relative to the first or second target (TARGET). Only a few measures of merit were found to measure the variation in design parameters successfully while being insensitive to pilot variability. However, pilot comments indicate that this is a very good maneuver to evaluate and demonstrate the benefits of high AOA pitch and roll capabilities.

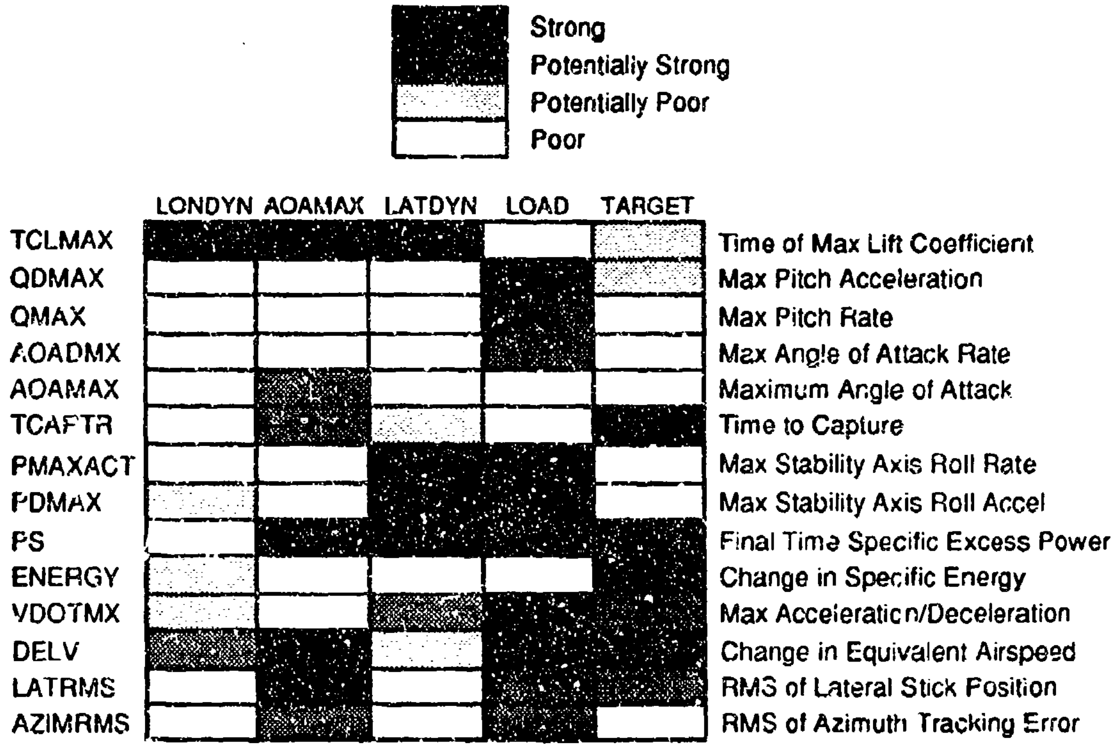


Figure 43. Overall Sensitivities for Dual Attack (STEM 4 TEST 1 ANALYSIS G)

STEM 5: Rolling Defense

To set up this maneuver, the pilot establishes a turn at the desired test conditions (AOA and airspeed, or load factor) and initiates a full stick roll over the top. The data taking portion of the maneuver begins when the pilot reaches the opposite 90° bank angle and applies a full forward stick input while maintaining lateral stick. The maneuver is terminated when the aircraft has unloaded. This maneuver is primarily intended as a control law evaluation maneuver to verify the nose-down pitch authority remaining while in a rolling condition. Additional information about roll coordination and maximum roll rate may also be obtained. Variations in maximum roll rate, center of gravity location, and pitch vectoring were tested using this maneuver. Figure 44 shows a summary of the measure of merit results from the maximum roll rate (PMAX) and center of gravity (DCG) variations. Several measures of merit were found to be sensitive to each of these design parameters. This indicates good repeatability in the maneuver and indicates that numerical data from this maneuver can be used to modify the design. Some pilot comments were also generated from this maneuver, but it tended to be very dynamic in nature and somewhat difficult to comment on.

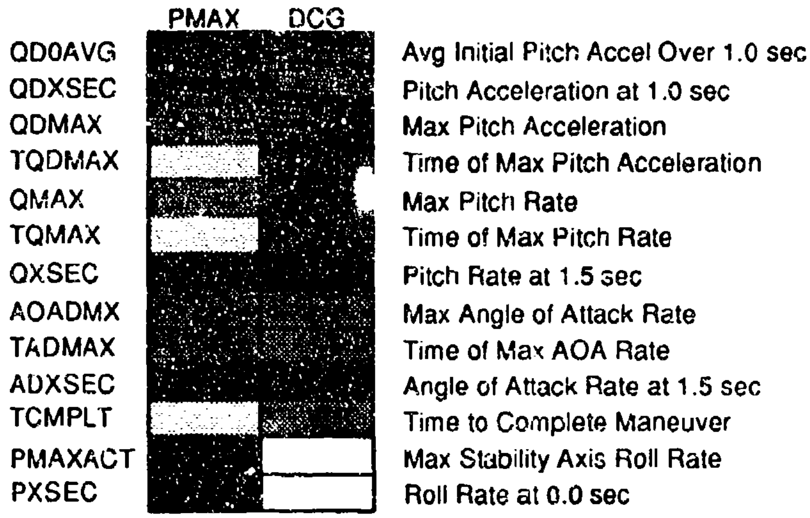


Figure 44. Overall Sensitivities for Rolling Defense (STEM 5 TEST 2)

STEM 6: Maximum Pitch Pull

This maneuver is very simple in that the pilot establishes the desired trim test point and then applies an aggressive full aft stick input and holds it until the pitch rate had stopped. This maneuver represents a fundamental element of several maneuvers by isolating an aggressive, open-loop longitudinal input. Testing was conducted at very low speed (V_{min}) and at corner airspeed (V_c). Variations in short period frequency (WSP), short period damping (ZSP), and maximum angle of attack (AOAMAX) were tested for the low speed case. Figures 45 and 46 show typical results for this testing and illustrate an important consideration when conducting measure of merit screening. Different indications of the sensitivity to design parameters were obtained between these figures because of the different range of AOAMAX tested. The range of WSP and ZSP for these two tests was identical, but the results in Figure 45 occurred when AOAMAX was varied between 40° and 70° whereas the results in Figure 46 are based on a variation between 40° and 55°. The large variation in AOAMAX used to produce Figure 45 tended to dominate the results. It resulted in a large number of black regions for the AOAMAX design parameter and reduced the strength of correlation for the other two design parameters. This example illustrates the fact that the measure of merit findings are dependent upon the ranges tested and that care must be taken when using DOE techniques so that the test matrix is balanced. However in general, the maximum pitch pull maneuver was useful in gathering quantitative data because it is a very simple, repeatable maneuver that isolates the pitch axis. Some pilot comments can also be obtained but it is not useful for flying qualities development because it is an open-loop maneuver.

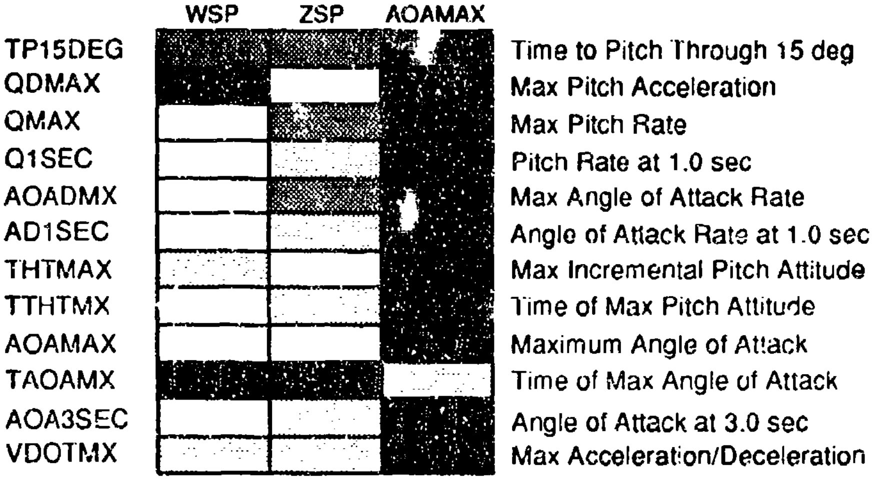


Figure 45. Overall Sensitivities for Max Pitch Pull (STEM 6 TEST 1 ANALYSIS A)

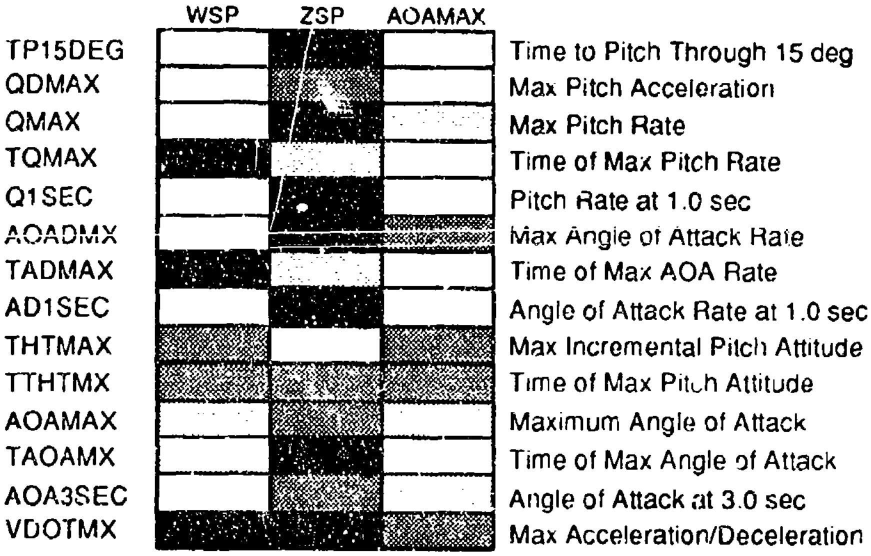


Figure 46. Overall Sensitivities for Max Pitch Pull (STEM 6 TEST 1 ANALYSIS B)

The maximum pitch pull maneuver was tested at corner airspeed also. The maneuver was initiated from a dive to allow a greater pitch angle change to be tested. Variations in Control Anticipation Parameter (CAP), short period damping (ZSP), and maximum attainable load factor (NZMAX) were tested for the corner airspeed conditio: Figure 47 shows typical measure of merit results for the higher speed case. Just as with the low speed version, quantitative data could be used to tie measures of merit back to design parameters, and some pilot comments were obtained.

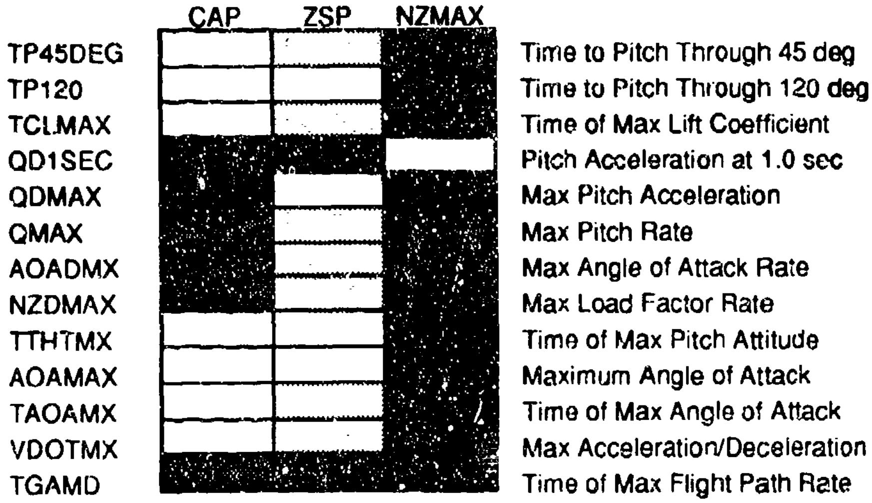


Figure 47. Overall Sensitivities for Maximum Pitch Pull (STEM 6 TEST 3)

STEM 7: Nose-Up Pitch Angle Capture

This maneuver setup is the same as STEM 6 and the maximum pitch attitude that can be captured is determined from STEM 6. A target aircraft is positioned ahead of and above the evaluation aircraft to provide a reference to capture. This maneuver represents a fundamental element of several maneuvers by isolating an aggressive longitudinal capture task. Testing was conducted at very low speed (V_{min}) and at corner airspeed (V_c). The low airspeed setup was tested with variations in short period frequency (WSP), short period damping (ZSP), longitudinal stick sensitivity (LONSNS), time delay (TIMDEL), and nonlinear stick shaping (LONSHP). The few measures of merit and design parameters that resulted in successful correlation are shown in Figure 48. Most of the measures of merit were dominated by pilot variability because of the closed-loop nature of the task. Time to capture was also calculated, but it was not effective because of the large amount of pilot technique required in this maneuver. The LONSHP design parameter did not generate any successful measure of merit correlations so it is not shown in Figure 48. However, this maneuver did generate very effective pilot comment data and Cooper-Harper ratings. All of the design parameters except for TIMDEL could be evaluated using pilot comment data. Historically it has been difficult to determine accurately the effects of moderate time delays in a fixed-base simulation.

The nose-up pitch angle capture maneuver was tested at corner airspeed also. The maneuver was initiated from a dive to allow a greater pitch angle change to be tested. Variations in Control Anticipation Parameter (CAP), short period damping (ZSP), and longitudinal stick shaping (LONSHP) were tested for the corner airspeed condition. Figure 49

shows typical measure of merit results for the higher speed case. Just as with the low speed version, very little quantitative data could be used to tie measures of merit back to design parameters. However, the time to capture metric proved more reliable for the higher speed test condition. Pilot comments and ratings were again very valuable for the corner airspeed test condition.

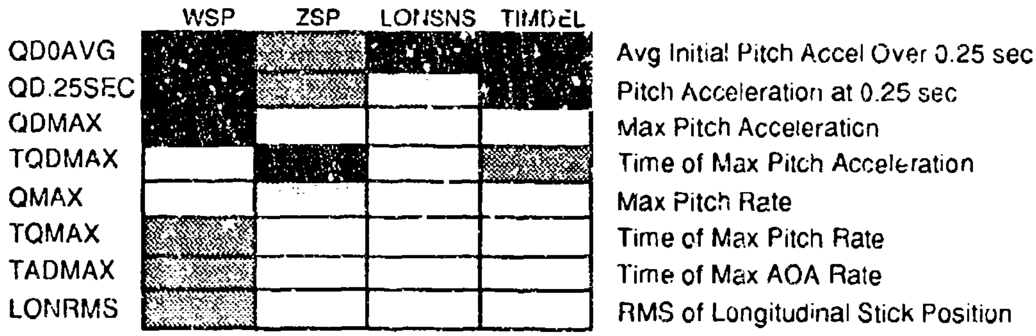


Figure 48. Overall Sensitivities for Nose-Up Pitch Angle Capture (STEM 7 TEST 7 ANALYSIS D)

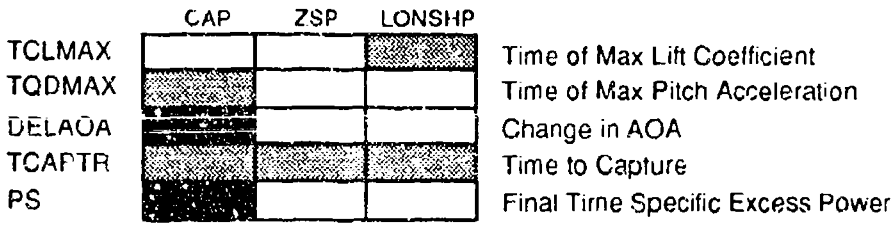


Figure 49. Overall Sensitivities for Nose-Up Pitch Angle Capture (STEM 7 TEST 6)

STEM 8: Crossing Target Acquisition and Tracking

This maneuver is conducted by setting up a target aircraft above the evaluation aircraft with a 90° heading offset, and the target immediately enters a turn toward the evaluation aircraft. The evaluation pilot tries to acquire rapidly and then continue tracking the target as it crosses in front. This maneuver allows the acquisition and tracking capabilities of an aircraft to be exercised through the multiple-axis acquisition of a target aircraft. The maneuver requires the test aircraft to generate and stop a pitch rate to capture the target, as well as perform a multiple axis tracking task on a crossing target. The ability to pull to moderately high AOA, stop the pitch rate, laterally track a target while unloading in AOA, and then transition to longitudinal tracking are tested. This maneuver was used to test variations in short period frequency, maximum roll rate, and roll mode time constant. Valuable pilot comments on longitudinal flying qualities, lateral flying qualities, and control harmony were obtained from this

maneuver. However, quantitative measures of merit were not calculated because of the freestyle nature of the task.

STEM 9: Pitch Rate Reserve

This maneuver is conducted by establishing a level turn at the desired test conditions and applying a full aft stick input. The input is maintained until the nose rate drops below its initial stabilized value. This maneuver is intended to demonstrate the reserve pitch authority available from a loaded condition. This maneuver was defined from the "Angular Reserve" maneuver tested in Reference 6. Design parameter variations in short period frequency (WSP), short period damping (ZSP), and longitudinal stick sensitivity (LONSNS) were tested. Figure 50 shows results of the measure of merit analysis conducted for this maneuver. Several measures of merit successfully correlated the simulation data indicating the ability to use quantitative data for this maneuver. The design parameter LONSNS did not generate significant changes in any of the calculated measures of merit. Some valuable pilot comment data was obtained using this maneuver, but it was limited because of the open-loop nature of the maneuver.

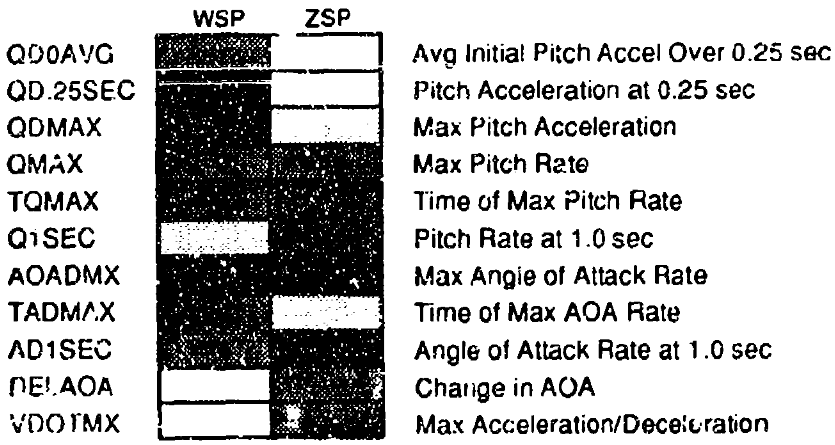


Figure 50. Overall Sensitivities for Pitch Rate Reserve (STEM 9 TEST 2)

STEM 10: High AOA Longitudinal Gross Acquisition

This maneuver is initiated with the evaluation aircraft in trail of a target aircraft. The target enters a turn and the evaluation pilot performs a sequence of longitudinal acquisitions of the target aircraft. With some practice, the pilot can perform the captures so that they occur around a test AOA. This maneuver is designed to isolate the flying qualities characteristics of an aircraft during a high AOA longitudinal capture task. It was developed and tested under MDA IRAD[20,32,34] and NASA sponsored[18,33] high AOA flying qualities criteria development

efforts. It is included as one of the initial STEMS maneuvers because of its applicability to high AOA and the fact that it is a relatively newly developed maneuver. This task has been used to develop longitudinal acquisition criteria for variations in short period frequency (WSP) and short period damping (ZSP) for several angles of attack. A minimal amount of data was taken under the STEMS contract. References 18, 20, 33, and 34 should be consulted for additional pilot comments, ratings, and flying qualities criteria obtained from this maneuver. Reference 33 also includes measure of merit analyses conducted with data from this maneuver. A summary of the measure of merit analysis conducted under the STEMS contract is shown in Figure 51. The few number of successful correlations in Figure 51 may be due to the minimal amount of data collected; Reference 33 was more successful at extracting meaningful measure of merit data from this maneuver. Overall, this task produces good flying qualities comments and data as well as providing some reasonably good quantitative information.

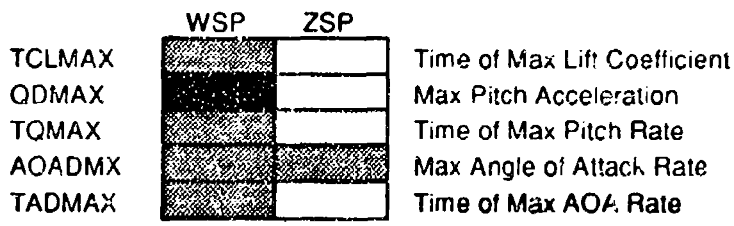


Figure 51. Overall Sensitivities for High AOA Longitudinal Gross Acquisition (STEM 10)

STEM 11: Sharkenhausen

This task is initiated with a head-on target aircraft that is downrange, offset, and higher than the evaluation aircraft. The evaluation pilot attempts to capture the target as rapidly as possible and then track the target. This maneuver allows the acquisition capabilities of an aircraft to be exercised through a multiple-axis acquisition of a target aircraft. The ability to pull to moderately high AOA and maintain good lateral control on a crossing target is emphasized. This maneuver was evaluated at a low speed condition (V_{min}) and at corner airspeed (V_c). Design parameters variations in longitudinal dynamics (LONDYN), lateral dynamics (LATDYN), and maximum angle of attack (AOAMAX) were tested for the low speed condition. The variation in longitudinal dynamics consisted of simultaneous variations in short period frequency and damping, and the variations in lateral dynamics were tested by simultaneously varying maximum roll rate and roll mode time constant. A quick investigation of initial range to target was also tested. A typical summary of the measure of merit data is shown in Figure 52. Some measures of merit were found to correlate to these design parameters; however, the data is very dependent upon initial range. This implies that the task

may be limited to simulation use. It does appear to be a valuable evaluation and demonstration maneuver however. The initial downrange could also be varied to determine the minimum range at which the task could be performed. Design parameters could then be varied to determine their influence on this minimum range.

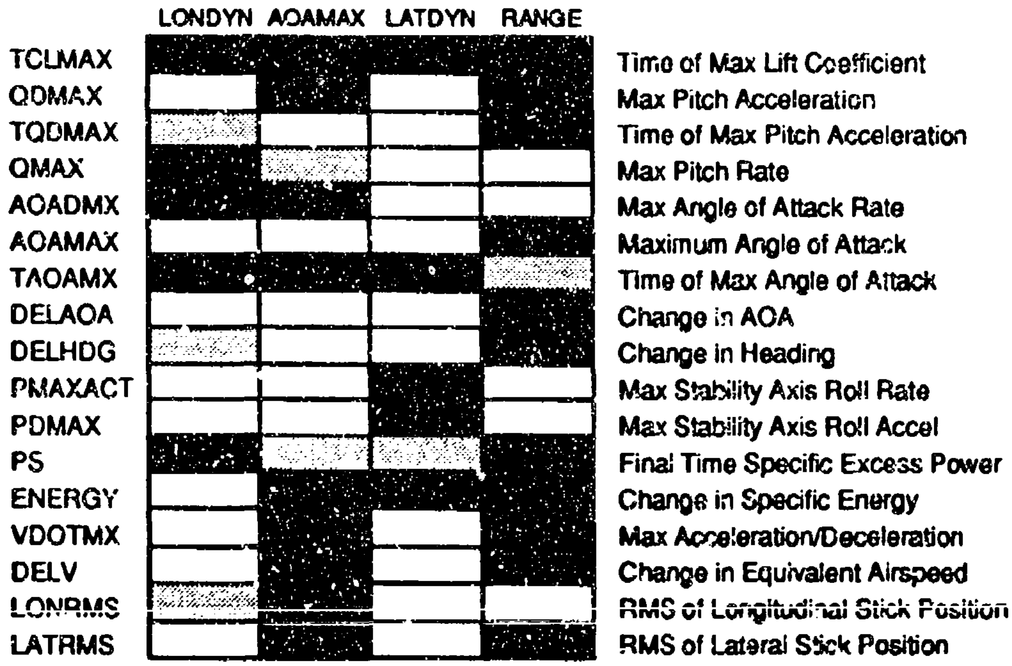


Figure 52. Overall Sensitivities for Sharkenhausen (STEM 11 TEST 5)

Variations in LONDYN, LATDYN, and AOAMAX were also tested with the Sharkenhausen at corner airspeed. A summary of the measure of merit analysis is shown in Figure 53. The high speed test condition seemed to be more dependent upon pilot technique because of the greater load factor capability. Very few strong correlations were observed and LONDYN resulted in no successful correlations. Overall, the initial range to target had a stronger influence on the measures of merit than did any of the design parameters tested. As a result, poor quantitative data resulted from this maneuver. However, this maneuver produced qualitative data that can be used as an overall check of the aircraft's ability to point at and track a crossing target rapidly.

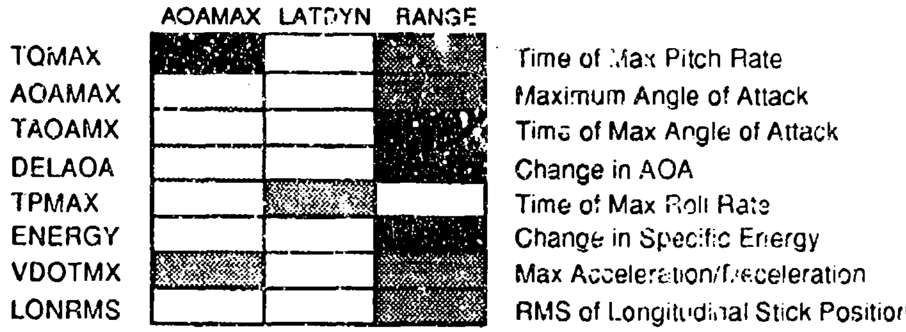


Figure 53. Overall Sensitivities for Sharkenhausen (STEM 11 TEST 4)

STEM 12: High AOA Roll Reversal

Setup for this maneuver is accomplished by performing a split-S, then pulling to the test AOA. The data gathering portion of the maneuver begins after the pitch attitude increases to the point that the velocity vector is pointed directly downward. At that time, the pilot applies a full roll control input and holds it until the heading has changed by the desired amount. The pilot then applies full opposite roll controls until returning through the initial heading. This maneuver allows the investigation of high AOA roll performance in a relatively stabilized flight condition. Roll onset as well as the aircraft response to a large cross-check input can be evaluated. This maneuver was originally suggested in Reference 6 and developed and tested under this research. This maneuver was flown using 90° and 180° heading changes. Variations in roll mode time constant (TR), maximum roll rate (PMAX), and whether or not a roll acceleration limiter existed (PDLIM) were tested. Figure 54 includes a summary of the overall measure of merit results for the 180° heading change. Maximum roll rate was the predominant design parameter in this case and PDLIM did not produce any strong correlation. Roll mode time constant and the roll acceleration limit were more important when the maneuver was flown through only a 90° heading change as seen in Figure 55. Maximum roll rate is still a stronger design parameter, but roll mode time constant and the roll acceleration limit are now significant. This may be attributed to the fact that the initial response is a much larger portion of the 90° maneuver than the 180° maneuver. Therefore, parameters that most affect the initial response become more of an influence. Overall, this maneuver was more effective at generating numerical data than pilot comments, but some useful comments were obtained.

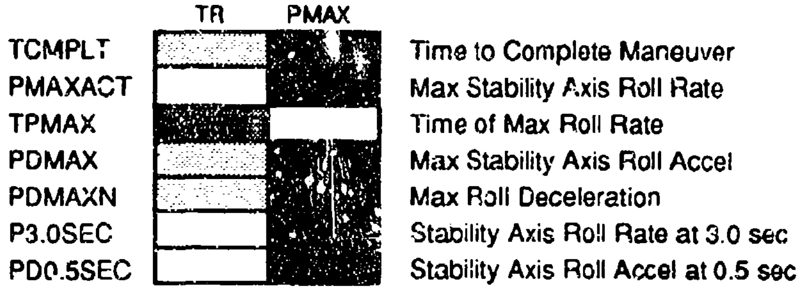


Figure 54. Overall Sensitivities for High AOA Roll Reversal (STEM 12 TEST 1)

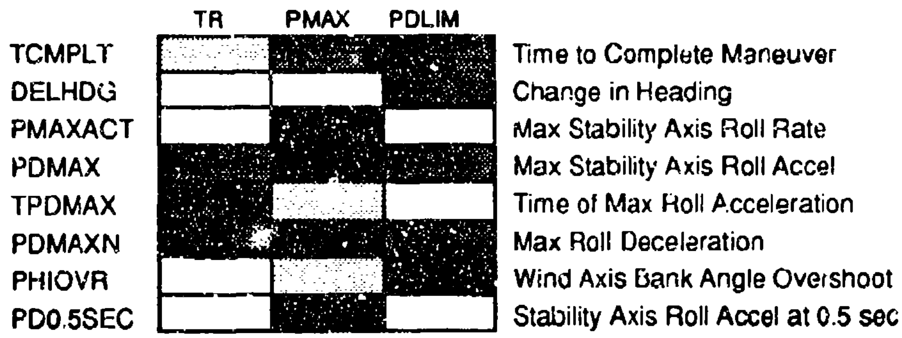
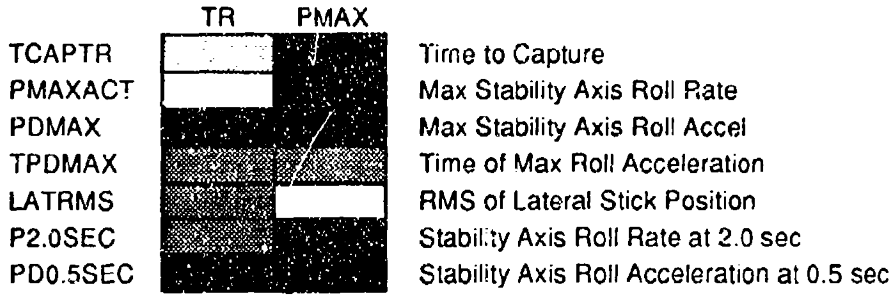


Figure 55. Overall Sensitivities for High AOA Roll Reversal (STEM 12 TEST 2)

STEM 13: High AOA Roll and Capture

This maneuver is initiated similarly to STEM 12, but the pilot performs a lateral capture instead of using full opposite roll controls to reverse the roll. The pilot can capture a heading because of the velocity vector is oriented straight down during this maneuver. This maneuver is designed to isolate the flying qualities characteristics of an aircraft during a high AOA lateral capture task. Figure 56 shows the measure of merit analysis for variations in roll mode time constant (TR) and maximum roll rate (PMAX). Data is only available for one pilot, so the correlations on this figure do not factor in pilot variability. As a result, a final conclusion on the strength of measures of merit cannot be determined yet, but the initial indications look promising. The pilot comment and rating data received from this maneuver appear to be valuable.



Note: Pilot Variability Not Included Because Data Available from Only One Pilot

Figure 56. Sensitivities to Design Parameters for High AOA Roll and Capture (STEM 13)

STEM 14: Minimum Speed Full Stick Loop

This maneuver is flown iteratively in a build-up fashion to identify an airspeed band in which a full-stick loop cannot be completed. The maneuver is started at a low speed and a maximum pitch pull is performed. The start speed is successively increased until an 80° pitch attitude is attained. The maneuver is then attempted at 100 knots faster than the speed required to reach 80° pitch attitude. This start speed is then successively reduced until the minimum pitch rate drops below 5 deg/sec or lateral control becomes deficient. Information on pitch authority at low speeds in the vertical as well as roll stability information may be obtained. It does not represent the minimum airspeed at which a loop can be flown using energy-maneuverability principles. This maneuver tends to be more of a demonstration and envelope expansion maneuver rather than a design evaluation maneuver. Therefore, the only variation tested was with the MuSIC aircraft with PST on and PST off. No quantitative data is intended to be calculated for this maneuver other than the minimum speed for a full stick loop. It did result in pilot comments about low speed controllability.

STEM 15: Minimum Time 180° Heading Change

This maneuver is intended to demonstrate the possible options that a pilot has available to change the aircraft heading by 180°. It should include testing of conventional methods such as level turns, the split-S, slices, as well as techniques such as the J-Turn. Only the initial and final conditions are specified for this maneuver. It is a freestyle maneuver because the pilot is encouraged to try various techniques to perform a 180° heading change. This maneuver was flown with the MuSIC simulation model using the PST on and off modes to demonstrate the additional options provided to a pilot through thrust vectoring. This maneuver is not intended for quantitative data except for a rough estimate of time required to change heading by 180°.

STEM 16 1-g Stabilized Pushover

To perform this maneuver, the pilot establishes a stabilized, wings level high AOA condition and aggressively applies full forward stick. The pilot continues to hold forward stick until the AOA drops below 10°. This maneuver allows a stabilized evaluation of the nose-down pitch authority at high AOA. This maneuver was developed and tested under NASA/Navy research[30]. It is included as one of the initial STEMS maneuvers because of its applicability to high AOA and the fact that it is a relatively newly developed maneuver. This maneuver was used to test variations in center of gravity location (DCG) and pitch vectoring (TV). Figure 57 shows measure of merit results from the DCG testing. Four center of gravity locations were tested. The column labeled DCGA compares the most forward cg location to the second most forward. The DCGB column compares the most forward cg to the third most forward, and the DCGC column compares the forward-most and aft-most cg locations. The measures of merit are quite good for the DCGA variation and continue to become stronger as the center of gravity location moves further aft. This maneuver generates very consistent quantitative data because of its simple, repeatable technique. Pilot comments and Pitch Recovery Ratings can also be used from this maneuver.

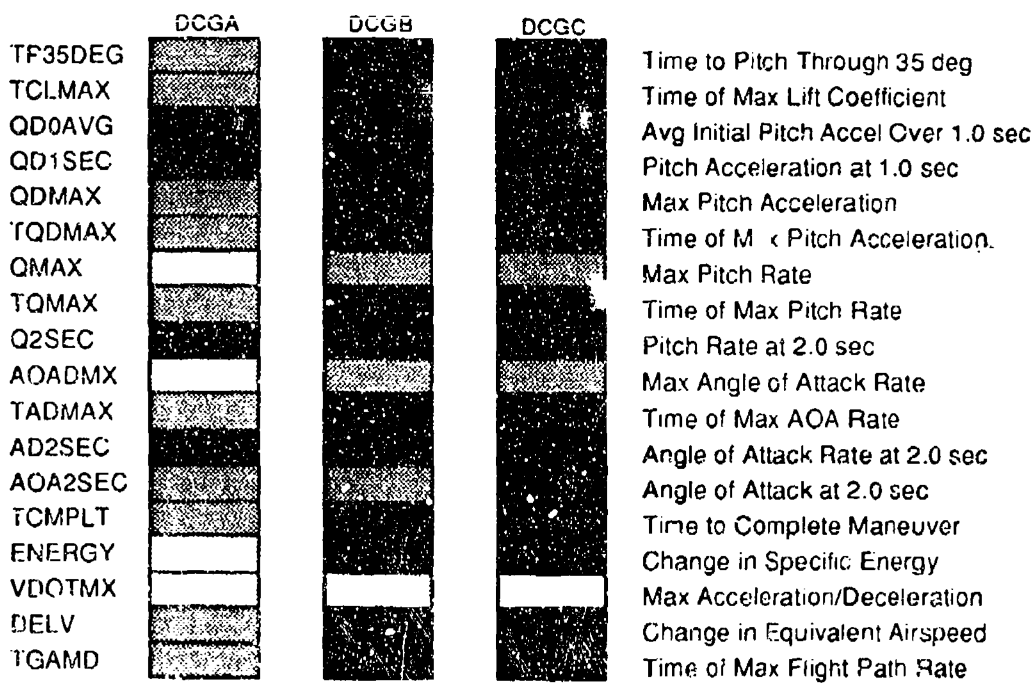


Figure 57. Overall Sensitivities for 1g Stabilized Pushover (STEM 16 TEST 2)

STEM 17 J-Turn

To perform this maneuver, the pilot applies full pitch and roll control inputs simultaneously until the aircraft has completed a 180° turn or reaches a wings-level inverted position, whichever occurs first. Then the pilot removes the roll control input and continues to pitch the nose back up to the horizon. This maneuver requires the simultaneous use of high AOA pitch and roll authority and serves as a good demonstration maneuver for high AOA maneuverability. The J-Turn is intended to emulate the maneuvering requirements of a tactic developed during the MuSIC thrust vectoring tactical utility studies.[23] This maneuver was used to investigate variations in short period frequency (WSP), maximum roll rate (PMAX), and longitudinal command types (CMDTYP). AOA and AOA rate longitudinal command types were compared. It was also used to compare the PST on and PST off modes of the MuSIC simulation model. Figure 58 shows a summary of the WSP, PMAX, and CMDTYP testing. For the measures of merit calculated, the variation in WSP resulted in the most correlations. However, both CMDTYP and PMAX resulted in several successful correlations. This maneuver also resulted in some pilot comments but seems to be best suited as a maneuver to demonstrate high AOA roll and pitch authority.

STEM 18: Tanker Boom Tracking

This maneuver consists of tracking the refueling probe of a tanker from a pre-contact position. The evaluation pilot can try tracking a steady probe or the boom operator can move the probe to create tracking errors. This maneuver is intended to evaluate high gain flying qualities. It will highlight high gain/high sensitivity flight control system deficiencies and possibly uncover low phase and gain margins. This is an existing maneuver but was further tested here for validation and because it may not be a well recognized evaluation maneuver. This maneuver is used at the Air Force Flight Test Center and in particular was recently used on the C-17 program.[35] Variations in Control Anticipation Parameter (therefore short period frequency), short period damping, and roll mode time constant were tested with the generic fighter and transport models. The variations in dynamics were discernible to the pilots and resulted in good comments. Cooper-Harper and PIO ratings are also applicable for this maneuver. This task was more difficult to fly in the fixed-base simulator than might be expected in flight. It appeared that PIO tendencies were exaggerated and it was more difficult to control the range to probe. These characteristics are attributed to the reduced pilot cues as compared to flight. It is still believed to be a valuable task; however, fixed-base simulation

may result in an overly pessimistic evaluation. Numerical measure of merit analyses were not attempted because of the tight closed-loop nature of this task.

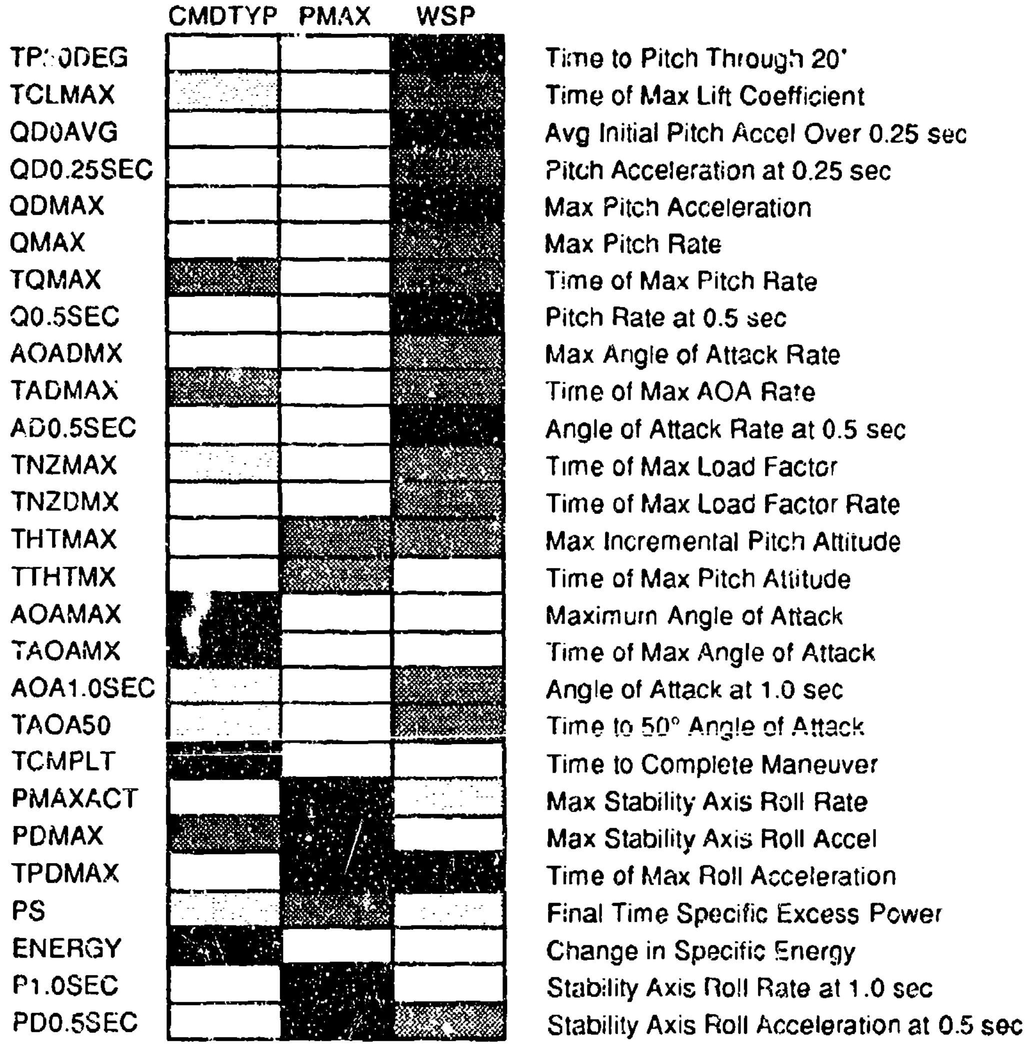


Figure 58. Overall Sensitivities for J-Turn (STEM 17 ANALYSES A and B)

STEM 19: Tracking in PA

This maneuver consists of tracking a target aircraft from approximately 1500 ft range while in a power approach mode and at an approach airspeed. It was valuable to have the target perform a sequence of heading changes to form a more demanding task. This maneuver is a task that can be performed at a safe altitude before precision landings are attempted. This was an existing maneuver but was further tested here for validation and because it may not be a well recognized evaluation maneuver. In particular, this maneuver was used on the F-15 S/MTD program.[36-40] Variations in Control Anticipation Parameter (therefore short period frequency),

short period damping, maximum roll rate (roll sensitivity), and roll mode time constant were tested with the generic fighter and transport models. The maneuver resulted in reasonably valuable comments and ratings from the fighter testing but the variations in dynamics were not very discernible during the transport testing. This may have been due to the design parameter range tested or the small heading variations of the target aircraft (15° heading changes for the transport task versus 30° heading changes for the fighter testing). Measures of merit were not calculated for this task because of the closed loop nature of the task. Additional testing and validation of the this maneuver is recommended; however, it appears to be a promising maneuver.

STEM 20 Offset Approach to Landing

This task is initiated with the aircraft on the correct glide slope, correct approach speed, and parallel to the runway but offset to one side. At a specified position, the pilot corrects the lateral offset and attempts a precision landing. This maneuver provides a demanding flying qualities task to test the ability to control flight path and speed while the aircraft is configured for approach. This maneuver has been used extensively to evaluate aircraft approach to landing flying qualities. Preliminary testing was conducted as part of this contract to investigate variations in maximum roll rate (PMAX), roll mode time constant (TR), Control Anticipation Parameter (CAP), short period damping (ZSP), engine response time constant (TAUENG), time delay (TIMDEL), and lift curve slope (LALPHA - pitch rate lead term). During testing, the aircraft speed control was found inadequate and that tended to dominate the pilot comments. At that point, testing was suspended because of the amount of data and testing that has already been conducted with this task in other research. Measures of merit were calculated from the limited testing conducted under the STEMS contract. Several measures of merit were attempted, but Figure 59 shows that few resulted in any success. This figure also indicates that only the PMAX, TR, and CAP design parameters resulted in any success. The nature of this task is such that it may require significantly more samples to produce a reliable statistical analysis. The pilot comments were difficult to analyze because of the speed control deficiency of the aircraft and the DOE test matrix chosen. (The seven factor test matrix shown in Figure 26 was used.) However, this maneuver is included in STEMS because it has proven to be a valuable evaluation tool in several other research and development programs.

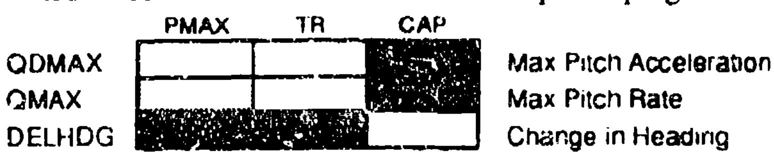


Figure 59. Overall Sensitivities for Offset Approach to Landing (STEM 20)

Chapter 6
Concluding Remarks

Three primary products resulted from this research. A Standard Evaluation Maneuver Set was initiated by developing and documenting several new maneuvers. These maneuvers are designed to help evaluate an aircraft in an operational environment and can be used to evaluate a wide range of aircraft attributes and capabilities. As a result, the maneuvers can be used throughout the design process to produce an operationally effective aircraft. These maneuvers have been documented in a maneuver reference guide that is intended to become a "living" reference source of useful evaluation maneuvers.[3] The maneuvers have been written in a somewhat generic form so that they can be altered as necessary to meet the specific test objectives for any aircraft program.

The second major product of this research is a maneuver development process that can be used to define additional evaluation maneuvers. The development of new maneuvers is important because the initial entries into STEMS do not provide a comprehensive set of evaluation maneuvers. The process documented within this report proved to be an effective method to develop and evaluate maneuvers. The key principles required to develop maneuvers, important characteristics of these maneuvers, and lessons learned are also described. This maneuver development process can be used to generate additional STEMS as new technologies emerge or new capabilities are added.

The third product of this research is a set of guidelines to help select existing maneuvers. It may not be necessary to test all of the STEMS maneuvers for a particular configuration or design parameter trade-off study. So, a set of guidelines has been developed to help STEMS users select the best subset of maneuvers for their particular test needs. These guidelines have been included with the maneuver reference guide[3] to create a stand-alone working document.

There are several benefits that can be gained through the use of these three products. High quality evaluation maneuvers can be developed more efficiently. The time required to test an aircraft can be reduced by using predefined, well-documented evaluation maneuvers. The time required to plan for a test can be reduced and the quality of the test can be improved by using the maneuver selection guidelines. And most importantly, a more constructive evaluation can be conducted by evaluating key aircraft attributes in operationally representative tasks.

Additional data on each successful maneuver tested during this simulation is documented in Reference 4. This data represents a large number of test points and may contain valuable

information for those who want to investigate these maneuvers further. For example, the pilot comments, ratings, and measure of merit data can be used to help develop initial test matrices for flying qualities criteria development or tactical utility studies. The data may also provide background data for the development and application of numerical measures of merit.

Chapter 7
Recommendations

The strongest recommendation for future efforts is to continue the development of new maneuvers for updates to the Standard Evaluation Maneuver Set. This research is just the first step toward a maneuver reference guide for the evaluation of a wide range of aircraft characteristics. STEMS will be an extremely valuable design tool if additional maneuvers continue to be added. Evaluation maneuvers that are developed in the future for emerging technologies should be included in this "living" document. It is also recommended that existing, well established maneuvers be included as part of STEMS so that they can be more uniformly documented and become more widely used. It is hoped that STEMS will be a convenient, and therefore often used, source of maneuver descriptions and ideas that will be used to improve an aircraft design from initial development in simulation to final flight test. New maneuvers or experience in applying existing STEMS maneuvers should be sent to Wright Laboratory/FIGC_2 for inclusion into STEMS.

The initial set of maneuvers was developed in a fixed-base simulation; therefore, it is recommend that in-flight testing be conducted to evaluate these maneuvers in a flight test environment. The maneuvers have already been shown to be valuable in simulation, but they need in-flight validation to determine if they can be used during flight test also. In particular, attributes such as repeatability, difficulty to set up, measurability, and safety need to be evaluated before these maneuvers can be used confidently. Some work has already been done through Air Force Test Pilot School projects and generally favorable results have been obtained. These projects were limited to relatively low AOA because of the aircraft available for testing. It would be beneficial to fly the high AOA evaluation maneuvers on the NASA F-18 HARV, F-16 MATV, NASA F-15 S/MTD ACTIVE, or X-31 because of their high AOA capabilities.

It would also be interesting to gather lessons learned from early flight test programs and determine if the STEMS maneuvers would have been able to detect deficiencies that were missed during design. If cases of PIO, roll ratcheting, or other deficiencies were uncovered during a flight test, it would be beneficial to have an evaluation maneuver capable of uncovering those deficiencies for future designs. If none of the current STEMS maneuvers can isolate the problem, then it would be valuable to develop a new maneuver to expose that deficiency and include it in STEMS.

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Appendix A
Additional Potential Maneuvers

An enormous number of potential maneuvers were considered during this contract but only a few were developed and tested in simulation. This appendix includes preliminary maneuvers from Phase I that were not tested during simulation because of time constraints. Some of these maneuvers may be valuable to further develop and add to STEMS. However, some of these maneuvers may duplicate other STEMS maneuvers or may not work well for evaluation, so they should be reviewed and compared to the current STEMS maneuvers before being developed during simulation. They are included in this appendix as a source of ideas for future development of STEMS.

Index of Additional Potential STEMS Maneuvers Found in Appendix A

STEM Candidate Number ###

Name	Short name for the maneuver
Status	STEMS candidate,Existing Eval., not STEMS Candidate
Type	Maneuver, Maneuver Sequence, or Freestyle Maneuver
Related STEMS	If the maneuver can be broken down into related STEMS for data analysis, then list them here

Applicable Classes and Flight Categories

Class	Cat	Phase
		List all applicable classes, categories and flight phases (MIL-STD-1797A)

Maneuver Description

A description of how the maneuver is to be flown

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
List the most important design parameters. Include paramaters which relate directly to design (e.g. control powers) as well as lumped parameters (e.g. LCDP)	List the performance objective that the pilot can achieve if the aircraft is properly designed. These are the results of properly reaching the design goals listed. For example, "Precise longitudinal pipper	This column contains general descriptions of the desired qualities of the maneuver. Some examples might include: longitudinal flying qualities, lateral agility, or instantaneous turn performance.	List both qualitative and quantitative measures of the aircraft's ability to perform the maneuver. For example, time to capture a bank angle, Cooper-Harper Rating, or maximum pitch rate would be appropriate here.	A description of how this maneuver would be used operationally, or what operational maneuver(s) is (are) simulated by this maneuver belongs in this column.

Comments:
This box is included for any additional comments.

Diagram:

STEM Candidate Number 265

Name	Straight and Level Acceleration
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
II, IV	A	CO

Maneuver Description

Begin in straight and level flight at idle power. Accelerate in maximum power to (Vc+Vmax)/2 while maintaining altitude.

Starting Conditions: 1.1 Vmin, (Vmin + Vc)/2, Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
FNP Drag T/W τENGINE Engine Rate Limits	Ability to accelerate quickly	Axial translation agility Axial maneuverability	Airspeed time history Acceleration time history Integral of Ps over 2 sec intervals Maximum ΔV in first 2 sec Maximum ΔEs in first 2 sec Time to reach Vc	Acceleration Acceleration for shot opportunity Exit from threat envelope Separate from threat Regain energy IRCM merge

Comments:

Grouping of maneuvers 18, 128, 129, 160, 199, 234, 253, 254, 264

Various starting speeds are used to test engine dynamics over a range of flight conditions.

First few seconds will be used to evaluate engine dynamics; whereas, the remainder of the maneuver is dominated by FNP, T/W, and drag.

Diagram:

STEM Candidate
Number 319

Name	Accelerate for Go-Around
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	C	WO

Maneuver Description

Begin in level flight with the aircraft configured for landing (gear and flaps as appropriate) and throttle at idle. Advance power to maximum and clean up aircraft to accelerate for go-around. Maintain level flight throughout maneuver. Accelerate until reaching x speed.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
FNP Drag T/W τ_{ENGINE} Engine Rate Limits	Ability to clean up aircraft and accelerate quickly without losing altitude	Axial agility Axial maneuverability	Airspeed time history Acceleration time history Integral of Ps over 2 sec intervals Maximum ΔV in first 2 sec Maximum ΔEs in first 2 sec Time to reach x speed	Accelerate for wave-off or go-around

Comments:	Diagram:

STEM Candidate

Number 320

Name	Optimum Acceleration
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
II, IV	A	CO

Maneuver Description

Begin at optimum load factor/AOA for acceleration performance and at idle power. Accelerate in maximum power to (Vc+Vmax)/2 while maintaining optimum load factor/AOA.

Starting Conditions: 1.1 Vmin, (Vmin + Vc)/2, Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
FNP Drag T/W τ_{ENGINE} Engine Rate Limits	Ability to accelerate quickly	Axial agility Axial maneuverability	Airspeed time history Acceleration time history Integral of Ps over 2 sec intervals Maximum ΔV in first 2 sec Maximum ΔEs in first 2 sec Time to reach Vc	Acceleration Acceleration for shot opportunity Exit from threat envelope Separate from threat Regain energy

Comments:

Diagram:

STEM Candidate Number 302

Name	Straight and Level Deceleration
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	B	DE
II, IV	A	CO

Maneuver Description

Begin in straight and level flight at maximum power setting. Reduce forward thrust to minimum (use idle power setting, maximum power and thrust reversing, or whatever technique is most appropriate for the aircraft being tested), employ all available drag devices, and decelerate to 1.1Vmin while maintaining 1g flight.

Starting Conditions: (Vmin + Vc)/2, Vc, 0.9Vmax(mil), (Vc + Vmax)/2

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
T/W τENGINE Drag Drag device dynamics and effectiveness Thrust reverser dynamics and effectiveness	Ability to decelerate rapidly in level flight	Axial agility Axial maneuverability	Airspeed time history Acceleration time history Integral of Ps over 2 sec intervals Maximum ΔV in first 2 sec Maximum ΔEs in first 2 sec	Emergency deceleration F-pole/A-pole straight ahead deceleration Reach optimum maneuver speed Formation rejoin

Comments:
Grouping of maneuvers 8, 10, 23, 40, 126, 131, 198, 236, 263

Various starting speeds used to test engine dynamics, drag device dynamics, and thrust reverser dynamics over a range of flight conditions.

First few seconds will be used to evaluate engine dynamics, drag device dynamics, and thrust reverser dynamics; whereas, the remainder of the maneuver is dominated by FNP, T/W, and drag.

Diagram:

STEM Candidate
Number 303

Name	Turning Deceleration
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, IV	A	CO

Maneuver Description

Begin at Vmax(mil) in military power. Enter a 3g turn and when airspeed reaches 0.9Vmax(mil), engage minimum forward thrust (use idle power setting, maximum power and thrust reversing, or whatever technique is most appropriate for the aircraft being tested) and pull into a maximum load factor (or maximum AOA) turn. Decelerate to Vc while maintaining 90° bank (±5°) and maintaining altitude ±100 ft.

Variations: Begin at (Vs + Vc)/2 and decelerate to 1.1Vmin.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ENGINE Drag, idle thrust Drag device dynamics and effectiveness Thrust reverser dynamics and effectiveness Control system pitch limiter Cmδ	Ability to decelerate rapidly	Axial agility Axial maneuverability Pitch agility	Time to decelerate Deceleration time history Airspeed time history Load factor time history Forward velocity time history Forward distance time history	Break turn Combat deceleration Force an overshoot Avoid an overshoot Deceleration to desired maneuvering speed

Comments:
Grouping of maneuvers 127, 133, 241

Diagram:

STEM Candidate
Number 325

Name	Axial Tracking
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase

Maneuver Description

Begin at IFR traffic pattern airspeed with a trimmed power setting. Hold IFR traffic pattern airspeed ±10 knots in atmospheric disturbances.

Variation: Begin at final approach speed with aircraft configured for final approach. Maintain final approach speed ±5 knots.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ENGINE Thrust axis control laws Udot/PLA dT/dV	Ability to maintain constant speed	Axial flying qualities	CHR Workload RMS speed error	Maintain desired airspeed

Comments:
Need to define standard set of atmospheric distubances for simulation.

Diagram:

STEM Candidate
Number 326

Name	Axial Acquisition
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase

Maneuver Description

Begin at (Vc + 20 knots) at a trimmed power setting in 1g level flight. Decelerate as rapidly as possible and capture Vc ±5 knots. Maintain constant altitude throughout maneuver.

Variations:
Begin at (Vc - 20 knots) at a trimmed power setting in 1g level flight. Accelerate as rapidly as possible and capture Vc ±5 knots.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ENGINE Thrust axis compensation Udot/PLA T/W	Ability to precisely control airspeed with throttle lever changes	Axial flying qualities	CHR Time to capture new airspeed	Decelerate or accelerate and stabilize on new speed

Comments:

Diagram:

STEM Candidate Number 323

Name	Fitch Unload from Clmax
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
II, IV	A	CO

Maneuver Description

Trim in a level turn at the AOA for Clmax and maximum power setting. Apply forward stick to capture to 0° AOA (±5°) for 2 seconds.

Starting Conditions: 1.1Vmin, (Vmin + Vc)/2, Vc (at Vc start at AOA for Clmax if attainable, otherwise start at [illegible] attainable AOA).

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Longitudinal control surface rate limit ω_{nsp}, ζ_{sp} $C_{m\alpha}$, $C_{m\delta}$	Ability to unload quickly from Clmax	Pitch agility Longitudinal flying qualities	Time to unload Initial pitch acceleration CHR AOA time history	Unload to accelerate

Comments:

Diagram:

STEM Candidate Number 237

Name	Bank-to-Bank Roll
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
II, IV	A	CO
II, III, IV	A	TF

Maneuver Description

Start in a turn at a 45° bank angle. Roll to the opposite 45° bank angle while remaining loaded. Maintain full roll controls until reaching opposite 45° bank angle. Reverse direction of roll immediately upon reaching opposite 45° bank angle. Continue rolling until roll through initial bank angle.

Variations:

Execute at 0.9Nzmax using 80° bank angles for initial conditions starting at Vc or higher.
Unload and load during reversals to maintain constant altitude.

Starting Conditions: 1.1Vmin, (Vmin + Vc)/2, 0.9Vmax(mil), (Vc + Vmax)/2

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τR, Pmax Cl_p, Cn_δ, Cl_δ Lateral control surface rate	Ability to roll quickly and change direction of roll rapidly	Roll agility	Total time Maximum roll rate Maximum roll acceleration Maximum roll deceleration Bank overshoot past 45° Maximum sideslip angle Lateral-directional coordination	Change planned maneuver plane

Comments:
Group III maneuver.

Diagram:

STEM Candidate Number 286

Name	Maximum Sideslip
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV II	A C	CO, GA PA

Maneuver Description

Begin in level flight with a thrust for level flight power setting. Achieve the maximum amount of sideslip angle while maintaining wings level. Conduct both to the right and left. Test for angles of attack up to AOAmax.

Variations:
Achieve and hold 2°, 5°, 10° sideslip angles.
Test rapid and gradual sideslip maneuvers.
Starting Conditions: 1.1Vmin, (Vmin + Vc)/2, Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ωnd, ζd, βmax, βdotmax Cnδ, Cnβ, Cyδ Clδ, Clβ	Ability to yaw quickly while maintaining wings level	Yaw agility Yaw flying qualities Departure resistance	βmax Time to βmax	Air-to-air gun snapshot Dynamic deceleration Guns defense air-to-air Defeats optical AAA tracker Strafing Useful for roll-coupled fuselage aiming

Comments:

Diagram:

STEM Candidate
Number 324

Name	Sideslip Tracking
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in 1g level flight. Target aircraft will begin ahead and to the left of evaluation aircraft (45° off nose). Target aircraft will pull into a right hand turn. When the target enters its turn, sideslip the evaluation aircraft as far as possible while maintaining wings level. As the target crosses the nose of the evaluation aircraft, capture the target in the reticle and continue to track it. Track the target as far as possible while maintaining wings level.

Starting Conditions: 1.1Vmin, (Vmin + Vc)/2, Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ωnd, ζd [$\zeta\phi\omega\phi/\zeta d\omega d$] βmax Lateral-directional control powers	Ability to track a target using sideslip only	Directional agility Directional flying qualities	RMS tracking error Time that target is within reticle Total change in sideslip angle while tracking CHR	Gun Snapshot Radar boresight acquisition

Comments:
Target maneuver needs to be defined through simulation.

Diagram:

STEM Candidate Number 79

Name	Arrest High Sink Rate
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	C	PA

Maneuver Description

Begin at approach AOA and minimum approach power. Establish the test glideslope. Arrest sink rate as quickly as possible without making power adjustments. Conduct maneuver while in landing configuration.

Variation: Perform with power on and power off.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
$1/T_{\theta 2}$ ω_{sp}, ζ_{sp} τ_{θ}	Arrest sink rate as quickly as possible for aborted approach.	Pitch maneuverability (for landing configuration) Pitch agility (for landing configuration)	Minimum altitude loss Initial pitch acceleration	Arrest high sink rate during approach High speed flame out approach (power off test)

Comments:
Test glideslope depends on aircraft. Some example test points would be: 4° for conventional aircraft, 6° for STOL aircraft, 15° for emergency landing

Similar to Navy pop-up maneuver.

Diagram:

STEM Candidate
Number 99

Name	Hammer Head
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin at V_c, pull vertical, unload, then at V_{min} conduct hammer head. Proceed into vertical dive and capture nose down vertical within ±10°.

Variation:
For multi-engine aircraft, may perform hammer head using asymmetric thrust.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{nd}, ζ_d Cn_β, Cl_β. Cn_δ Engine Separation LCDP $Cn_{\beta_{APP}}$	Ability to yaw at low speed	Yaw agility	No departure Minimum uncommanded roll during yaw Time to complete	Vertical reverse Vertical scissors

Comments:
Includes maneuver 100.

Significant pilot skill required.

Diagram:

STEM Candidate Number 7

Name	Freestyle Low-Speed Acceleration
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	C	TO, CT, WO
IV	A	CO

Maneuver Description

Begin in straight and level flight at 1.1Vs, maximum power. Accelerate in optimum manner and maintain or regain starting altitude. Finish at Vc.

Variations:

Perform starting in both clean and landing configurations.

Begin at H=15K, end at best cruise/dash Mach and altitude.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Ps τ_{ENGINE}	Low speed acceleration Low speed pitch rate Low speed pitch acceleration	Axial agility Pitch agility (negative) Maneuverability Low speed flying qualities	Minimum time to complete maneuver	Low speed acceleration maneuver (freestyle) Takeoff/Waveoff

Comments:

Diagram:

STEM Candidate
Number 23

Name	Dynamic Deceleration
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in straight and level flight, maximum power. Decelerate in optimum manner for 2 sec.
Starting Conditions: (Vs+Vc)/2, Vc, Vmax(mil).

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Cd Cd speedbrake Cd vs CL FN_{PIDLE}	Pitch rate, pitch acceleration Roll rate, roll acceleration Yaw rate, yaw acceleration Engine transients Drag devices transients and effectiveness Fs	Axial agility Pitch agility Yaw agility Axial flying qualities Deceleration performance	Maximum Δhorizontal forward velocity in 2 sec Minimum horizontal distance traveled in 2 sec Maximum deceleration	Forcing overshoot Avoiding overshoot Combat deceleration

Comments:

Diagram:

STEM Candidate
Number 130

Name	Precise Speed Control
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	B	CR, LO, RT, AD
II, III, IV	A	RR

Maneuver Description

Hold xxx knots ± xx knots while maintaining altitude. Conduct at Vend and Vcruise. Conduct in clean air.

Design Paramsters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Thrust axis compensation τ_{ENGINE} Udot/PLA dT/dV	Ability to maintain constant speed	Axial flying qualities	Workload CHR Velocity deviation	Cruise Extended formation ASLAR (Aircraft Surge Launch and Recovery - must hold accurate 300 kt airspeed)

Comments:
Task primarily measures workload to maintain speed - becoming more difficult with improved engines.

Diagram:

STEM Candidate
Number 131

Name	Precise Speed Control
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	B	CR, LO, RT, AD
II, III, IV	A	RR

Maneuver Description

At Vend, increase speed 5 knot, hold 30 sec, decrease back to Vend - 5 knot, hold 30 sec, accelerate to Vend
Repeat at Vmarrange

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τ_{ENGINE} Thrust axis compensation Longitudinal compensation $d\gamma/dV_{APP}$ dT/dV Udot/PLA	Ability to control speed with throttle lever changes	Axial flying qualities	Workload CHR	Holding IFR Cruise Formation corrections

Comments:

Diagram:

STEM Candidate Number 154

Name	Guns Jink
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Pitch Attitude Capture Pitch Unload Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in wings level at $(V_s + V_c)/2$ or V_c. Pull into a 20° climb, push over to -1 g, roll 180°. Also perform push overs to -2 and -3 g's.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
		Agility	Minimum time to roll 180° to inverted flight	"Jink", destroy gun snapshot solution

Comments:

Diagram:

STEM Candidate Number 83

Name	Multiple Rolls
Status	STEMS Candidate
Type	
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, IV	A	

Maneuver Description

Conduct two 360° rolls at 1, 3, 5 g's.
Starting Conditions: 1.1Vs, Vc, Vmit

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τ_R Pmax Control power Surface rate Control law compensation ω_ϕ/ω_d	Roll acceleration Departure resistance	Lateral flying qualities	No AOA, sideslip oscillations Roll rate No departure	

Comments:
Tests control system compensation in addition to departure resistance. Most aircraft prohibited from multiple rolls. Tests control law compensation and integrator response.

Diagram:

STEM Candidate
Number 111

Name	Point Rolls
Status	STEMS Candidate
Type	
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, IV	A	

Maneuver Description

Conduct 2, 3, 4 point rolls

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{nsp}, ζ_{sp} τ_R ω_{nd}, ζ_d Rate limits Gradients ARI	CAP' Roll acceleration P/Flat Pdot/Flat	Lateral flying qualities Harmony Bank angle capture ability	Average P ϕ over/under CHR	

Comments:

Diagram:

STEM Candidate Number 24

Name	Defensive Spiral
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	Roll and Capture Pitch Attitude Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Start in a level turn, at maximum AOA, 1.1 Vs, maximum power, clean configuration. Perform loaded maximum rate roll and pull to 90° nose down (±10°) attitude at maximum AOA. Minimize altitude loss in optimum manner while maintaining maximum roll rate until reaching 45° nose low attitude. Level off in optimum manner.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	High AOA roll rate High AOA roll acceleration High AOA engine transients and operation Low speed drag device effectiveness Low speed pitch rate Low speed pitch	Lateral flying qualities Maneuverability	Minimum altitude loss Time to complete maneuver	Simulated defensive spiral

Comments:
NEEDS BETTER DEFINITION.

LEVEL OFF IN OPTIMUM MANNER - FOR WHAT PURPOSE? IS THE LEVEL OFF PART OF THE MANEUVER?

Diagram:

STEM Candidate Number 91

Name	Deceleration to Loaded Roll Underneath
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Turning Deceleration Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	

Maneuver Description

Begin at 1.5Vs, H=20K. Perform a loaded deceleration at AOAmax (or AOA for Clmax) to stagnation speed. Loaded roll underneath back to level turn and capture bank within ±10°.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τ_R Pmax Surface size	Roll acceleration	Low speed maneuverability P_s Lateral flying qualities	Time to complete roll Airspeed change during roll Altitude loss during roll	Guns defense

Comments:

Diag ...:

STEM Candidate

Number 2

Name	Freestyle Roll and Capture
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO, GA, WD

Maneuver Description

Begin in level turn at $0.9g_{max}$ ($0.9AOA_{max}$) in maximum power. Roll 90° (±10°) and capture bank angle in optimum manner. Finish with $N_z \geq 0.9G_{MAX}$ ($AOA \geq 0.9AOA_{max}$).
Starting Conditions: Start at 1.1 Vc for $0.9g_{max}$ maneuver. Start at (Vs + Vc)/2 for $0.9AOA_{max}$ maneuver.
Variation: Perform 180° (±10°) roll and capture.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Pmax, τ_R Pdotmax $Cn\delta$, $Cl\delta$ P/Flat Hinge moments Flexibility Rate limits $\Delta\beta max$ $[\zeta\phi\omega\phi/\zeta d\omega d]$	Ability to rapidly and precisely change bank angle	Roll agility Pitch agility Lateral flying qualities	CHR Time to roll and capture 90° (180°)	Quarter plane roll and lift vector placement Guns jink

Comments:

Diagram:

STEM Candidate Number 176

Name	90° Roll and Vertical Scan Track
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Level Turn Longitudinal Gross Acquisition Lateral Gross Acquisition Longitudinal/Lateral Tracking

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

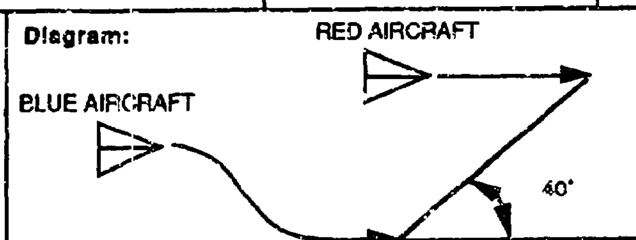
Gets tally inside 10 nm at 40° break lock, select vertical scan (VS). Hard left to get VS track. Measure time to track.
Starting Conditions: Vs, (Vs + Vc)/2, Vc, Vmax(mil).
See drawing

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Ability to roll rapidly to capture a bank angle	Pitch agility Roll agility Maneuverability Flying qualities Controllability	Time to roll 90° and capture ±3.5° (VS envelope)	90° roll and vertical scan track

Comments:
IS THIS MORE OF A FUNCTION OF AVIONICS THAN ANYTHING ELSE?

ANYTHING NEW OVER ROLL CAPTURES? PUTS A TOLERANCE ON ROLL CAPTURE, BUT CAN INCLUDE THIS TOLERANCE FOR A ROLL CAPTURE.

Diagram:



STEM Candidate
Number 309

Name	Barrel Roll
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, IV	A	CO, GA

Maneuver Description

Begin in straight and level flight at Vc. Perform a maximum radius barrel roll so that airspeed is approximately 60-100 kts when inverted.
Variation:
Perform barrel roll to kill overshoot and stabilize on new velocity.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
wnsp, zsp tR, Pmax Cnd, Cld [zfwf/zdwd] CnβAPP	Roll control at elevated g Harmony between longitudinal and lateral axes Roll acceleration Pitch acceleration	Lateral flying qualities Low speed controllability Longitudinal flying qualities Maneuverability	Speed over the top Time to new velocity	Displacement roll Part of a pop-up ground attack Missile defensive High g barrel roll defense

Comments:
Grouping of maneuvers 95, 185, 243.

Diagram:

STEM Candidate
Number 94

Name	
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Barrel Roll AOA Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

From Vc + 100, approximately 15° nose low, wind up to a high g, level turn. Perform a 3/4 barrel roll over the top (Vmin ≈ 100 kn) to wings level inverted, pull up to C_{Lmax}, reverse 1/2 barrel roll back to level flight.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τ_R Control power	Ps T/W W/S Turn rate Roll acceleration Pitch acceleration Pmax	Maneuverability Longitudinal agility	Minimum ground track during reversal No departure Velocity vector acceleration Roll acceleration Time to complete	One variation of a 1 turn rolling scissors after an in close gun defense Force overshoot

Comments:

Diagram:

STEM Candidate
Number 248

Name	Roll Agility Task 1.0
Status	STEMS Candidate
Type	Maneuver
Related STEMS	Lateral Gross Acquisition Lateral Tracking

Applicable Classes and Flight Categories

Class	Cat	Phase
I, IV	A	CO, WD

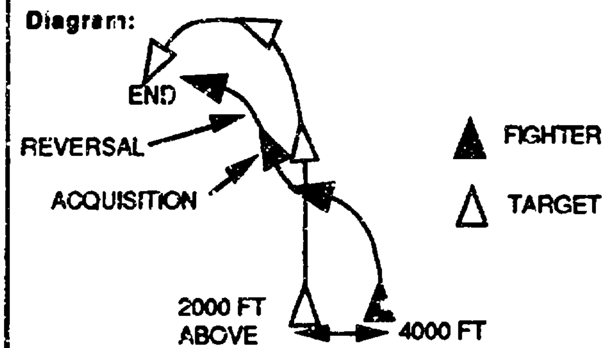
Maneuver Description

AFTPS Roll Agility Task 1.0.
Set up: Target 4000 ft abreast and 2000 ft above the fighter.
Maneuvering: At the "action" call, the fighter performs a constant g turn level turn toward the target maintaining altitude separation. When the fighter crosses target six o'clock (with a 90° aspect angle) it performs a rolling pull-up to acquire, as quickly as possible, the target. At the same time the target, at the "crossing six" call, commences a constant g level turn into the fighter. The fighter will acquire the target and maintain acquisition (target in the pipper) through an aileron reversal.
Performance standards: Desired - Maintain target inside a 50 mil diameter reticle during the aileron reversal. Adequate - Maintain target inside a 100 mil diameter reticle during the aileron reversal.
See drawing.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τ_R, Pmax, Pdotmax Cn_δ, Cl_δ $[\zeta_\phi\omega_\phi/\zeta_d\omega_d]$ $\Delta\beta max$ $\omega_n d\zeta_d$	Ability to rapidly roll and capture a target and track the target	Roll agility Lateral gross acquisition flying qualities Lateral tracking flying qualities	CHR Time to capture from crossing "six" Deviation outside desired capture Time outside desired	Missile/gun acquisition and tracking

Comments:
Group II maneuver.

Diagram:



STEM Candidate Number 45

Name	Circling Approach to Landing
Status	STEMS Candidate
Type	
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
II	C	PA

Maneuver Description

Capture glide slope, maintain glide slope and localizer, fly to minimum descent altitude (MDA), circle to land on desired runway, maintain MDA while circling. Conduct in turbulence and gusts. Simulate ceilings of 300 ft. and 500 ft. Simulate visibility of 3/4, 1, 1 1/2 nm.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
$1/T_{\theta 2}$, $d\gamma/dV$ ω_{nsp}, ζ_{sp} ω_{BWe}, $\omega_{BW\gamma}$ $\tau_{e\theta}$ τ_R ω_{nd}, ζ_d $[\zeta_\phi\omega_\phi/\zeta_d\omega_d]$ $\tau_{e\phi}$ ϕ_1	Course tracking Flight path control Roll control	Divided attention maneuver Longitudinal and lateral flying qualities Pitch and roll harmony	CHR Localizer deviation Glide slope deviation Airspeed deviation Altitude deviation	Circling approach and landing (final approach segment)

Comments:
NEED BETTER DEFINITION - START/END CONDITIONS

Need to be able to standardize gusts, shears, and timing for occurances.

Diagram:

STEM Candidate
Number 318

Name	Non-Precision Approach and Landing
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Instrument Approach, Intermediate Segment STEM 42) Offset Approach to Landing (STEM 299) Circling Approach to Landing (STEM 45) Precision Landing

Applicable Classes and Flight Categories

Class	Cat	Phase
I, II, III, IV	C	PA, L

Maneuver Description

Begin maneuver as if it were an ILS approach; but on final, execute a side-step maneuver to land on the parallel runway (if no parallel runway, side-step to correct given offset) and land aircraft.
Variations: On final, execute a circling maneuver to land on desired runway.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{nsp}, ζ_{sp} $1/T_{\theta 2}$, t_{ss} τ_R, $t_{\phi,\phi}$ ω_{nd}, ζ_d $[\omega_\phi\zeta_\phi/\omega_d\zeta_d]$	Pitch-roll control harmony Flight path control Roll control	Maneuverability Longitudinal flying qualities Lateral flying qualities Controllability	CHR Touchdown precision Speed deviation Flight path deviation Course deviation	Side-step approach and landing Circling approach and landing

Comments:

Diagram:

STEM Candidate

Number 46

Name	Visual Approach, Down Wind and Base Legs
Status	STEMS Candidate
Type	
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
[illegible]	C	PA

Maneuver Description

Enter downwind leg opposite touchdown point. Start base leg 45° past threshold using 30° bank while simultaneously reducing power to begin descent. Continue turning to final from base leg and align with runway while descending. Conduct in turbulence and in gusts.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{nsp}, ζ_{sp} $t_{e\theta}$, τ_R ω_{nd}, ζ_d $t_{e\phi}$ $[\zeta_\phi \omega_\phi / \zeta_d \omega_d]$	Flight path control Heading control Roll control	Divided attention maneuver	CHR Flight path deviation Speed deviation	Visual approach and landing (down wind and base legs)

Comments:

STEM 46, 298, and 297 comprise a Manauver Sequence for a visual approcach and landing.

Need to be able to standardize gusts, shears, and timing for occurances.

NEED BETTER DEFINITION - START/END CONDITIONS

Diagram:

STEM Candidate
Number 178

Name	Takeoff
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Maximum Rate Roll Bank Capture Turn

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CT, TO

Maneuver Description

5000 ft landing configuration, gear/flaps down. Straight and level at break-ground speed. Execute maximum performance roll/turn. Time stops when velocity vector moves 30° with no altitude loss.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Ability to maneuver aircraft at low speed to avoid collision	Agility Maneuverability	Time to change velocity vector heading by 30°	Take-off avoid bird strike. Maximum performance roll to 60° bank, 30° heading change

Comments:

Diagram:

STEM Candidate
Number 70

Name	Minimum Controllable Airspeed on Climb-Out or Landing
Status	STEMS Candidate
Type	Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
[illegible]	C	L
[illegible]	B	CL

Maneuver Description

From straight level flight (take-off or landing configuration) cut engine power, maintain original heading (±2°), altitude (±50 ft.) and no more than 5° bank.
Variation: Conduct from crabbed position also.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{nd}, ζ_d $\delta r/\beta$ $Cn_{\beta DYN}$ V_{MCA}	Heading control authority Speed control Control heading, attitude, and altitude of aircraft with loss of engine	Heading control flying qualities Controllability Pitch control flying qualities Roll control flying qualities	Amount of rudder deflection Difficulty of heading control $V_{MCA} > V_{SO}$ CHR Deviation of heading Deviation of altitude	Minimum controllable airspeed (critical engine out)

Comments:
This maneuver is to demonstrate that $V_{MCA} > V_{SO}$ and at VMCA that the aircraft is controllable

Diagram:

STEM Candidate
Number 11

Name	Scissors
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Level Turn Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in straight and level flight, maximum power. Perform maximum AOA level 90° course change (±10°), maximum rate reversal, second maximum AOA level 90° turn in opposite direction. Finish with $H_{END} \geq H_{START}$. Also conduct in military power setting.

Variations:
Conduct loaded and unloaded reversals.
Conduct maneuver at Vstagnation.
Conduct constant altitude reversals (rolling push pull) and non-constant altitude reversals.
Starting Conditions: Vstagnation, 1.2Vs, (Vs + Vc)/2

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Pmax, τ_R ω_{nsp}, ζ_{sp}	Low speed roll rate Low speed roll acceleration Low speed pitch rate Low speed pitch acceleration Low speed turn radius	Low speed roll agility Low speed turn performance Maneuverability Longitudinal-lateral harmony (for constant altitude reversals)	Minimum downrange travel Minimum time to complete maneuver CHR	Minimum radius turns/Simulated flat scissors

Comments:
Includes STEM 85, STEM 89

Diagram:

STEM Candidate

Number 153

Name	High g Reversal
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Level Turn Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in wings level flight. Roll to 90° bank angle and establish maximum pitch rate (9g/full aft stick). Turn 45° and reverse while loaded. Capture opposite 90° bank angle.

Starting Conditions: Conduct at (Vs + Vc)/2, Vc, and Vmax(mil).

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
		Roll agility Lateral flying qualities	Minimum time to turn 45° and complete reversal, 90° opposite bank (±10°) CHR No departure	Counter high angle gun shot, reverse on overshoot to offensive position.

Comments:

Similar to maneuver 11.

CHANGE HEADING OR COURSE BY 45°?

MANEUVER MAY BE DOMINATED BY AOAmax - IF AOAmax EXCEEDS 45°, YOU DON'T TURN MUCH.

IS THIS COVERED BY ROLL AND CAPTURE MANEUVER?

Diagram:

STEM Candidate Number 93

Name	One-Circle Lead Turn
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Level Turn Roll and Capture Maximum Pitch Pull

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CC

Maneuver Description

Start at H=20K, Vc. Conduct a loaded deceleration, level turn at AOA for Clmax (or AOAmax). Continue through 180° level turn. Perform a loaded roll to inverted, complete split-S reversal. $\psi_{END} = \psi_0$. Maintain maximum power throughout maneuver.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
CLmax, aCLmax Fs/a Control power	W/S T/W Roll acceleration Pitch acceleration Yaw acceleration Turn rate Turn radius	Roll agility	Time to change ψ 180° Time to change θ 180° Total time to complete Altitude change Stagnation load factor (N_{ZSTAG})	One variation of a one circle fight.

Comments:

Diagram:

STEM Candidate Number 15

Name	Freestyle Slow-Speed Turn
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO, WD

Maneuver Description

Start with 45° (±2°) nose high, $V_{S(1g)}$, maximum power. Change heading 180° in optimal manner and capture heading ±2° and pitch 45° (±2°) nose high for 2 sec. Finish with $H_{END} \geq H_{START}$.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Low speed pitch rate Low speed pitch acceleration Low speed roll rate Low speed roll acceleration Low speed yaw rate Low speed yaw acceleration	Pitch agility Roll agility Yaw agility Low speed turn performance Gross acquisition flying qualities Maneuverability	Minimum time to complete maneuver CHR	Slow speed turn to tracking solution

Comments:

Diagram:

STEM Candidate
Number 62

Name	Aerial recovery
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	[illegible]

Maneuver Description

Aerial recover

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
$1/T_{\theta 2}$ ω_{nsp}, ζ_{sp} $\omega_{BW\theta}$, $\omega_{BW\gamma}$ $\tau_{e\theta}$	Precise flight path control	Longitudinal flying qualities	CHR	Aerial recover

Comments:
NEED BETTER DEFINITION

Diagram:

STEM Candidate
Number 66

Name	Air drop
Status	STEMS Candidate
Type	
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase

Maneuver Description

Air drop

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Controllable response to large, rapid changes in weight and CG while at slow speed	Longitudinal flying qualities	CHR Workload	Air drop

Comments:
NEED BETTER DEFINITION

Diagram:

STEM Candidate Number 59

Name	Collision Avoidance
Status	STEMS Candidate
Type	Maneuver
Related STEMS	Load Factor Capture Maximum Pitch Pull Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
[illegible]	B	CR, D, CL
[illegible]	C	TO, PA, L

Maneuver Description

From level flight, rapidly and aggressively roll into a bank of at least 60° while simultaneously pulling-up (or pushing-over) to obtain limit load factor of 2.5g (-1.0g in push-over).

Variations:

Follow heads down display TCAS commands.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
$1/T_{\theta 2}$, $N_{z max}$ ω_{nsp}, ζ_{sp} $\omega_{BW\theta}$ τ_R ω_{nd}, ζ_d $[\zeta_{\phi}\omega_{\phi}/\zeta_d\omega_d]$ ϕ	Ability to change flight path rapidly Ability to change flight path accurately	Turn radius (in all axes) Pitch agility Roll agility Maneuverability	Initial climb/descent rate Initial pitch acceleration Initial roll acceleration Slant range from predicted impact point at predicted impact time	Traffic collision avoidance (open or closed-loop)

Comments:

Diagram:

STEM Candidate Number 65

Name	Combat Descent
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Maximum Rate Roll Roll and Capture Maximum Pitch Pull Pitch Attitude Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	

Maneuver Description

From level flight, H=20K, Vc, roll to inverted flight, pull to 45° nose low attitude, roll upright. Hold 45° nose low, and increase airspeed to Vmrt. Level off at 500 ft.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Rapidly descend from cruise altitude to enter low level ingress portion of a mission	Pitch agility Roll agility Flying qualities Maneuverability	CHR Time to descend	Combat descent from high altitude to low level flight

Comments:

Diagram:

STEM Candidate Number 13

Name	Freestyle Nose-High Reversal
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO, WD

Maneuver Description

Begin in vertical flight (±5°), at $V_{S_{ne}}$, maximum power, lower nose in optimum manner to capture and track a target 90° to either side and 45° below horizon. Capture target within ±2° and track for 2 seconds.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{nsp}, ζ_{sp} P_{max}, τ_R	Pitch rate Pitch acceleration Roll rate Roll acceleration Yaw rate Yaw acceleration	Pitch agility Roll agility Yaw agility Gross acquisition flying qualities	Minimum time to capture and track target CHR	Nose high reversal (freestyle)

Comments:

Diagram:

STEM Candidate
Number 29

Name	Slow Speed Attack
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	Longitudinal Gross Acquisition Lateral Gross Acquisition Longitudinal Tracking Lateral Tracking

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO, WD

Maneuver Description

Begin in straight and level flight at maximum power at 1.1Vs. Capture and track (±2°) target at 1:30, 45° high for 2 sec.
Variation: Capture right (left) side of 45° pitch ladder marker.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Pdotmax, τR qdotmax, ωmax ωnsp, ζsp T/W	Low speed roll rate Low speed roll acceleration Low speed pitch rate Low speed pitch acceleration Low speed yaw rate Low speed yaw acceleration	Pitch agility Roll agility Yaw agility Longitudinal flying qualities Lateral flying qualities Control harmony	Minimum time to track target 2 sec	Slow speed AIM-9 shot against a target at 1:30, 45° high

Comments:
NEEDS TARGET MANEUVER DESCRIPTION

Diagram:

STEM Candidate Number 26

Name	Guns Jink
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	Roll and Capture Maximum Pitch Pull Pitch Attitude Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in a level turn, maximum AOA, maximum power, (Vs+Vc)/2. Perform maximum rate roll in optimum manner to inverted attitude (±10°), pull maximum AOA until pitch attitude is -90°, perform maximum rate 180° roll (±10°) in optimum manner, pull maximum AOA to wings level flight.
Variation: Conduct at Vstagnation

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Pdotmax, τR qdotmax, qdotmin Cmα, Cmδ ωnsp, ζsp αmax	Low speed roll rate Low speed roll acceleration Low speed pitch rate Low speed pitch acceleration	Roll agility Torsional agility Pitch agility Instantaneous turn performance Lateral flying qualities Low speed turn performance	Minumum time to complete maneuver Maximum change in velocity vector orientation CHR Altitude loss	Simulated slow speed guns defensive maneuver

Comments:	**Diagram:**

STEM Candidate Number 96

Name	Immelmann
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

At H=15K-20K perform Immelman (1/2 loop, 1/2 roll) at progressively lower airspeed. Maintain altitude at top of loop (Hend = Hmax) and capture heading ±2° at top of loop. Perform at military and maximum power.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
C_{Lmax} τR Control power	T/W W/S Roll acceleration Pitch acceleration	Low speed controllability Acceleration performance Lateral flying qualities Pitch agility Low speed turn performance	Vmin to start maneuver Time to complete maneuver Minimum airspeed loss Minimum altitude gain	Minimum speed to go up Vertical conversion on target aircraft for missile employment

Comments:
Includes maneuver 274

Diagram:

STEM Candidate Number 143

Name	Pitch Back
Status	STEMS Candidate
Type	Maneuver
Related STEMS	Maximum Pitch Pull Maximum Rate Roll

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in straight and level flight, execute full aft, full right stick input (flight control permitting, alternative is pilot maximum performance). Time stops when both heading and pitch attitude change 45°. Maneuver is performed without a capture at the end.
Variations: Conduct at speeds 1.3Vs and Vc.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Pdotmax, τR qdotmax, ωnsp	Simultaneous roll and pitch change	Flying qualities Maneuverability Agility Harmony	Minimum time to point nose 45° in two planes No departure CHR	Snapshot opportunity with target 45° right and 45° high Guns defense

Comments:
Similar to maneuver 29

Maneuver can be performed with o" "ne simulation.

Diagram:

STEM Candidate Number 163

Name	*Reattack*
Status	STEMS Candidate
Type	*Freestyle Maneuver*
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO, WD

Maneuver Description:

Begin at H=30K, meet target head-on at +2000 ft. Maximum level turn to put target that flies straight ahead in boresight circle.
Starting Conditions: (Vs + Vc)/2, 1.2Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Minimum time turn through 180° heading change.	Maneuverability Flying qualities Agility	Minimum time crossing until target in boresight circle Minimum range to target in boresight circle	Employ MRM on target attempting to blow through on merge Achieve tracking solution on non-maneuvering threat

Comments:
Includes maneuver 164.

Similat to STEM 113.

Diagram:

STEM Candidate
Number 110

Name	Rolling Attack
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Barrel Roll Longitudinal Tracking Lateral Tracking Rolling Pull-Up

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	GA, WD

Maneuver Description

From low altitude, high speed, 3/4 barrel roll to nose low, 270° bank. Acquire and track ground reference point for 5 sec, RPO to low altitude, high speed egress

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
ω_{sp}, ζ_{sp} τ_R ω_d, ζ_d ARI/RAI Gradients	β/ε CAP' Yaw acceleration Directional dropback Fs/Nz P/Flat	Harmony Longitudinal flying qualities Lateral flying qualities Directional flying qualities Roll agility Maneuverability	CHR RMS mil deviation	Rolling attack

Comments:
NEEDS BETTER DEFINITION.

START/END CONDITIONS?

Diagram:

STEM Candidate

Number 138

Name	Snapshot
Status	STEMS Candidate
Type	
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in wings level flight at H=10K. Track nose along horizon (±3°) at maximum rate using pitch and roll combined. Measure heading rate (ψdot).
Starting Conditions: 1.2Vs, (Vs + Vc)/2, Vc.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Ability to position nose of aircraft in front of target for gun shot	Pitch and roll agility Flying qualities in tracking on horizon Tracking flying qualities Control harmony	Altitude change Rate of change of velocity vector Minimum speed Time to acquire horizon	Snapshot during low speed fight

Comments:

Diagram:

STEM Candidate
Number 142

Name	Split S
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in level flight at H=15K. Execute maximum performance roll/pull to initiate split S. Time stops when nose passes 90° low
Starting Conditions: Vs, 1.5 Vs, 2Vs
Variations:
When nose passes 45° low, roll out and pull to level flight.
Use power as necessary to minimize altitude loss.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Pdotmax, τ_R qdotmax, AOAmax ω_{nsp}, ζ_{sp}	Pitch acceleration	Roll agility Pitch agility	Minimum time to point nose toward bandit plane of maneuver Minimum turn radius Minimum altitude loss Maximum Ps at end of maneuver	Low speed lead turn Defensive turn in vertical

Comments:
Includes STEMS 103 and 136.

Diagram:

STEM Candidate Number 173

Name	Tracking
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

From 6000 ft trail, target aircraft begins maximum performance barrel roll. Test tracking with caged pipper.
Starting Conditions: $(V_s + V_c)/2$, $1.2V_c$, V_{max}(mil)

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
P_{max}, τ_R ω_{nsp}, ζ_{sp}	Ability to precisely track a maneuvering target	Flying qualities Maneuverability	CHR RMS tracking errors Time outside desired mil deviation Number of excursions outside desired mil deviation	Gun track rolling adversary

Comments:
TASK IS HIGHLY DEPENDENT UPON RELATIVE PERFORMANCE OF TARGET/SHOOTER

NEED BETTER DEFINITION - AT 6000 ft IS THIS DONE WITH SMALL PITCH AND ROLL INPUTS OR SHOULD YOU DO A BARREL ROLL ALSO?

Diagram:

STEM Candidate Number 266

Name	Transition from Defense to Attack
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Level Turn Lateral Gross Acquisition Longitudinal Gross Acquisition Longitudinal/Lateral Tracking

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO, WD

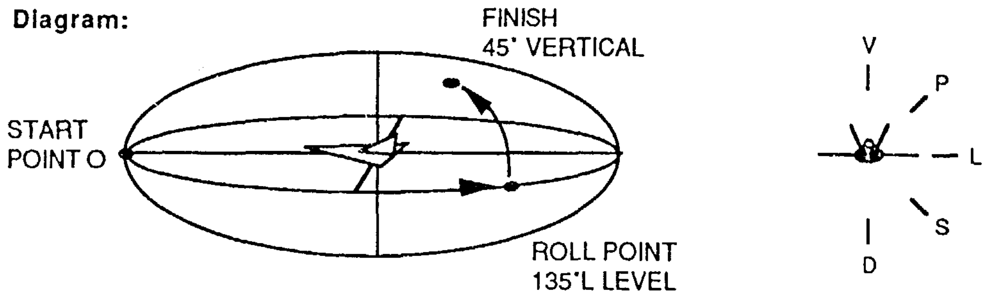
Maneuver Description

Set speed and altitude in level flight. Track point 0. Perform single plane turn until nose passes through roll reference point; tracking is not required. As nose transits through the roll reference point, immediately roll to achieve tracking at the best available launch parameters on the final reference point. Reference point 1 defines the roll transition point and reference point 2 defines the end game when tracking is achieved. Repeat for left and right turn direction. Repeat for pitch plane and slice plane of turn ar shown below (V-vertical, P-pitch, L-level, S-slice, D-down).
Reference Point: Reference point 1 at 90° right or left, or 180°.
Starting Conditions: 1.2Vs, Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
		Pitch acceleration Pitch rate Pitch control Roll acceleration Roll rate Deceleration Acceleration	Ps Ps rate Airspeed change Pitch/vel vec rate Roll rate	While performing a maneuver in one plane of motion: 1. Attack a target that is not in the current plane 2. Achieve best launch parameters in min time 3. Enter safe zone to "jam" attacker

Comments:

Diagram:



STEM Candidate Number 148

Name	Vertical Lead Turn
Status	STEMS Candidate
Type	
Related STEMS	Pitch Attitude Capture Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Pull to 60° nose high, then roll 180°, and pull to 45° nose low. Conduct at 1.2Vs, (Vs + Vc)/2, Vc.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
	Good pitch rate/acceleration Good roll rate/acceleration	Pitch agility Roll agility Turn performance	Minimum time for reversal from (60° nose up to 45° nose down)	Counter target in vertical CIC maneuver Lead turn

Comments:
NEEDS MORE PRECISE DEFINITION - HOW SHOULD THE PULL BE CONDUCTED, HOW SHOULD THE ROLL BE CONDUCTED?

Diagram:

STEM Candidate Number 97

Name	Vertical Reverse
Status	STEMS Candidate
Type	
Related STEMS	Pitch Attitude Capture Pitch Unload Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

From approximately Vc, pull to vertical, unload, roll 180°, push out at minimum speed to level flight.
Variation: While vertical, begin tail slide. Pull stick back (nose will pitch down), catch attitude in level flight at Clmax or maximum AOA.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
wnsp, zsp CLmax, aCLmax, amax Control power Cma Cnβ, Cnβdyn T/W, W/S	Pitch acceleration Longitudinal stability	Low speed controllability Acceleration performance Maneuverability Pitch agility Departure resistance	Vmin to recover level ΔEs Time to complete No departure Minimum altitude loss (from tail slide to level flight)	Vertical reverse

Comments:
Includes STEM 108

Diagram:

STEM Candidate
Number 281

Name	
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Pitch Attitude Capture Roll and Capture

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	CO

Maneuver Description

Begin in level flight. Pull to 45° and hold for 2 sec. Roll inverted and return to start altitude.
Starting Conditions: 1.2Vc, Vmax(mil); Altitudes = 200 ft/500 ft/ 1000 ft/5K.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
			Minimum time to complete Minimum Airspeed Loss Minimum Altitude Gain	Low altitude missile employment

Comments:
NEED BETTER DEFINITION - CAPTURE ALTITUDE, ROLL UPRIGHT, END CONDITIONS?

Diagram:

STEM Candidate Number 87

Name	
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Turning Deceleration Pitch Unload Maximum Rate Roll Maximum Pitch Pull

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	

Maneuver Description

Initiate decelerating level turn at Vc. At Vc/2, simultaneously unload and roll inverted. At a 180° bank angle, add full aft stick while still rolling.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
Surface rate Control power Inertia compensation	Pitch acceleration Yaw acceleration Roll acceleration	Departure resistance Flying qualities	No departure No roll reversal Time to complete	Roll, reacquire, reattack One variation of a 1 circle fight

Comments:

Diagram:

STEM Candidate
Number 201

Name	
Status	STEMS Candidate
Type	Maneuver Sequence
Related STEMS	Straight and Level Acceleration Level Turn Lateral Gross Acquisition Lateral Tracking

Applicable Classes and Flight Categories

Class	Cat	Phase
IV	A	

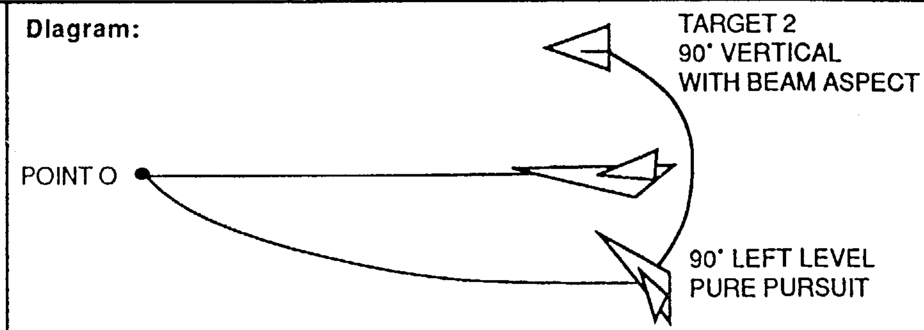
Maneuver Description

Set speed/altitude in level flight, track point 0. On command, perform single plane turn until nose passes through target 1; tracking is not required. As the nose transits through target 1, immediately roll to achieve tracking at the best available launch parameters on target 2. End maneuver when tracking is achieved at best achievable weapons parameters.
Target: Target 2 always starts at 90° vertical. Target 1 starts at 90° right or left, or 180°. Both targets perform pure pursuit attack. Both targets begin at gun range (<2.5 NM)
Starting Conditions: 1.2Vs, Vc

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
P_{max}, τ_R ω_{nsp}, ζ_{sp}	Pitch control as roll and acceleration vary Roll control as pitch and acceleration vary	Maneuverability Agility Flying qualities	Ps, Psdot Airspeed change Pitch/vel vec rate Roll rate	Attack target in different plane Enter "safe" zone, ie. "jam" attacker Negate attackers front quarter weapons envelope

Comments:
Set up could be extremely difficult in flight.

Diagram:



STEM Candidate
Number 184

Name	Terrain Following/Terrain Avoidance
Status	STEMS Candidate
Type	Freestyle Maneuver
Related STEMS	

Applicable Classes and Flight Categories

Class	Cat	Phase
I, IV	A	

Maneuver Description

Fly a slalom or dolphin course. Perform slalom and dolphin individually or simultaneously. Fly various courses to exercise various speeds.

Design Parameters	Performance Objectives	Maneuver Attributes	Measures of Merit	Operational Task
τ_R Stick harmony $1/T_{\theta 2}$ ω_{nsp}, ζ_{sp} $\omega_{BW\theta}$, $\omega_{BW\gamma}$ $t_{e\theta}$ $t_{e\phi}$		Small amplitude tracking	Time to complete Integral of error Spacial compression for controllability check CHR	

Comments:
BEING DEVELOPED BY TOM CORD.

Includes STEM 64.

Diagram:

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